CREATING MUSICAL CADENCES VIA CONCEPTUAL BLENDING: EMPIRICAL EVALUATION AND ENHANCEMENT OF A FORMAL MODEL

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THE COGNITIVE THEORY OF CONCEPTUAL BLENDING may be employed to understand the way music becomes meaningful and, at the same time, it may form a basis for musical creativity per se. This work constitutes a case study whereby conceptual blending is used as a creative tool for inventing musical cadences. Specifically, the perfect and the renaissance Phrygian cadential sequences are used as input spaces to a cadence blending system that produces various cadential blends based on musicological and blending optimality criteria. A selection of "novel" cadences is subject to empirical evaluation in order to gain a better understanding of perceptual relationships between cadences. Pairwise dissimilarity ratings between cadences are transformed into a perceptual space and a verbal attribute magnitude estimation method on six descriptive axes (preference, originality, tension, closure, expectancy, and fit) is used to associate the dimensions of this space with descriptive qualities (closure and tension emerged as the most prominent qualities). The novel cadences generated by the computational blending system are mainly perceived as single-scope blends (i.e., blends where one input space is dominant), since categorical perception seems to play a significant role (especially in relation to the upward leading note movement). Insights into perceptual aspects of conceptual bending are presented and ramifications for developing sophisticated creative systems are discussed.

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NEW CONCEPTS MAY BE CREATED EITHER BY "exploring" previously unexplored regions of a given conceptual space (exploratory creativity), transforming established concepts in novel ways (transformational creativity), or making associations between different conceptual spaces that share some structural relations (combinational creativity). Boden (2004) maintains that the latter (i.e., combinational creativity) has proved to be the hardest to describe formally. This paper explores aspects of combinational creativity in the domain of music, and more specifically, the harmonic structure of music.

Conceptual blending is a cognitive theory developed by Fauconnier and Turner (2003) whereby elements from diverse but structurally related mental spaces are "blended," giving rise to new conceptual spaces that often possess new powerful interpretative properties and allowing better understanding of known concepts or the emergence of novel concepts altogether. Conceptual blending theory is useful for explaining the cognitive process that humans undergo when engaged in creative acts, and is akin to Boden's notion of combinational creativity. A computational framework that extends Goguen's formal approach (Goguen, 2006) has been developed in the context of the COINVENT (Concept Invention Theory) project (http://www.coinvent-project.eu) (Schorlemmer et al., 2014). According to this framework, two *input spaces* are described as sets of weighted properties and relations, and after their *generic space* is computed, the *amalgamation* process (Eppe et al., 2015) leads to the creation of consistent blends that are optimal according to some criteria relating to the blending process and to the knowledge domain of the modeled spaces (the amalgamation process potentially includes multiple "generalization paths," leading to many different blends).

With regard to music, conceptual blending has been predominantly theorized as the cross-domain integration of music structural and extramusical domains such as text or image (e.g., Cook, 2001; Moore, 2012; Zbikowski, 2002, 2008). Additionally, it has been studied in the context of "musicogenic" meaning (Koelsch, 2013), which refers to physical, embodied, emotional, and personality-related responses to music; such studies include work on music and motion by Johnson and Larson (2003) or empirical studies on pitch perception and image schemata in children by Antović (2009, 2011). Finally, there have been studies that touch upon issues of structural mappings/blending between different spaces

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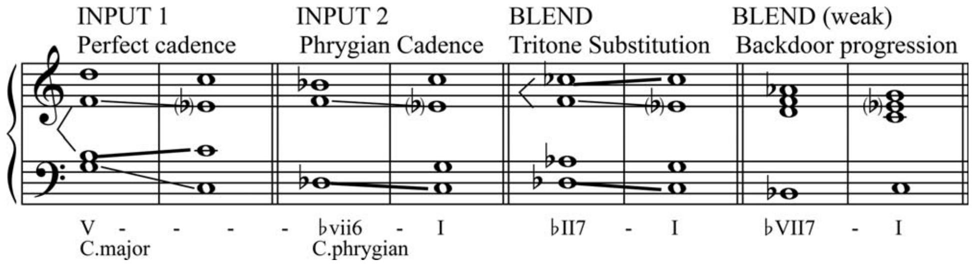

FIGURE 1. Conceptual blending between the tonal perfect cadence and a Renaissance Phrygian cadence gives rise to the tritone substitution progression / cadence (the backdoor progression can also be derived as a blend).

within the music structure domain per se (such as mappings between incongruous tonalities (Ox, 2014) and different tonal pitch space theories (Spitzer, 2003)). Almost all of the above studies examine conceptual blending in retrospect, analyzing and explaining existing metaphors/blends rather than taking a bottom-up, creative perspective of *generating* novel blends. A more extended discussion and critical examination of conceptual blending processes in music is presented by Stefanou and Cambouropoulos (2015).

In this paper it is maintained that the creative potential of conceptual blending (i.e., invention of new blends) in the domain of music is, probably, most powerfully manifested in processes that enable structural blending. To substantiate this potential, a proof-of-concept autonomous computational creative system that performs melodic harmonization is being developed (Kaliakatsos-Papakostas, Makris, Tsougras, & Cambouropoulos, 2016). A core component of this system is a transition blending mechanism that has been applied, among other things, to well-defined harmonic concepts such as harmonic cadences (Eppe et al., 2015; Zacharakis, Kaliakatsos-Papakostas, & Cambouropoulos, 2015). The present work focuses on conceptual blending of musical cadences (with well-established functional/voice-leading characteristics) and reports in detail algorithmic and empirical findings that relate to its application. The particular focus on cadences comes from the fact that they constitute one of the most salient harmonic concepts and are of major importance in tonal music. The significance of the cadence lies not only in its form-creating function (i.e., the delineation of phrase/group boundaries that give rise to hierarchical grouping structure), but also in that its harmonic content contributes, to a considerable extent, to the special character of a harmonic idiom in which it functions as an indispensable closure element (e.g., Aldwell & Schachter, 2003; Bigand & Parncutt, 1999; Caplin, 2004; Huron, 2006, Chapter 9, pp. 143-174; Sears, 2015). The insight obtained by this proof-of-concept approach will be exploited to develop a system capable of performing harmonic blending between different musical idioms in a melodic harmonization task.

The blending methodology is applied to two distinct cadential chord sequences, i.e., sequences that serve as cadences when encountered at the end of musical phrases/sections: the tonal perfect cadence sequence, as encountered in 18th and 19th century tonal music and the modal Phrygian cadence sequence, as encountered in 16th century (Renaissance) modal music (Figure 1). The perfect cadence is described as a functional dominant-to-tonic chord progression (Aldwell & Schachter, 2003; Caplin, 1998; Sears, 2015) consisting of a $V^{(7)}$ chord in root position—prepared by a chord with pre-dominant function—leading to a I chord in root position and with the tonic in the upper voice (^1). The three- or four-voice Phrygian cadence is described as a contrapuntal progression (Barnett, 2002; Collins Judd, 2002; Schubert, 2008) based on a two-voice linear movement consisting of a $\flat vii^6$ chord leading to a I or i or I_{omit3} chord with the tonic in the upper voice (^1) (see Figure 1).[1]

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[1] Both cadential progressions originate from the two-voice clausula, called simple (Zarlino, 1558), parallel (Dahlhaus, 1990), or standard model cadence (Schubert, 2008), featuring stepwise motion 7-8 and 2-1 and the progression from the imperfect consonance M6 to the perfect consonance P8. (For modes lacking the M6, like Dorian, Mixolydian, and Aeolian, the leading note was created through musica ficta, while in the Phrygian mode the leading note was resolved with downward semitonal motion.) According to Dahlhaus (1990, and also in his article on "Harmony" in GMO), this two-voice clausula evolved gradually into the four-voice tonal cadential progression through the addition of a leap of a fourth or fifth on the fifth and first degrees of the mode in the lower voice (bass). A similar descending fourth leap cadence may also appear in the Phrygian mode, with the bass falling from the seventh to the fourth degree of the mode (Schubert, 2008), but it was much less common. When tonal harmony was established, besides the upward leading note, the cadential bass became fixed, while the Phrygian cadence was abandoned due to its downward leading note (however, its voice-leading concept can be found in the iv^6-V half cadence type).

These two cadential progressions have been chosen for the present empirical research, among many other candidates, because they are maximally different from each other regarding their two basic elements: the treatment of the leading note and the motion of the lower voice. In particular, the perfect cadence has an upward leading note, while the Phrygian cadence a downward one, and in the perfect cadence the bass moves by an upper fourth/lower fifth leap, while in the most frequent Phrygian cadence the bass moves by a downward second. Other types of cadences ending on the tonic chord (this excludes the half cadence) have at least one of these elements in common, so they do not create maximally different pairs. This maximal difference is important for the design of the empirical experiment, as explained later in the paper.[2]

For the purposes of blending, the cadences are modeled as rich concepts that embody several properties. Thus, the above two cadences are represented not only as chord types but, additionally, as collections of notes and note transitions with weights attached to each note or note transition based on functional/voice-leading properties, such as semitonal resolution of the leading note, type of harmonic progression expressed as distance between chordal roots, the existence of the tritone in the penultimate chord of the perfect cadence (lines in Figure 1 indicate important notes relations and note transitions). For instance, in the perfect cadence, the upward leading note is probably the most salient component of the penultimate chord, as it appears in all the main dominant chord types (V, V^7 and vii^o). The root and the seventh of the dominant chord are salient but hypothetically less so than the leading note, and the fifth of the dominant is the least important component, as it can be omitted in certain cases. Accordingly, in the Phrygian cadence, the most characteristic component of the penultimate chord is the downward leading note (downward semitone movement: ^2 to ^1). The root is salient but hypothetically less so (upward whole tone movement: ^7 to ^8) and the fifth is the least salient element of the chord. In short, the most prominent characteristics of the two cadences are assumed to be the upward leading note of the perfect and the downward leading note of the Phrygian cadence; however, in the case of the perfect cadence sequence, two more features can be considered as having significant weight: the fourth (or fifth) leap in the bass (Barnett, 2002, p. 448; Caplin, 2004, pp. 66-76; Dahlhaus, 1990, pp. 83-94), and the resolution of the tritone (it can be argued, following Rameau, that the resolution of the tritone to imperfect consonance in the tonal V^7-I progression is the counterpart of the motion from imperfect to perfect consonance characteristic of pre-tonal music). The two input spaces (perfect and Phrygian) are represented as being equally important in the blending process; however, we expect the perfect cadence to be more prominent as a cadential schema in the mind of contemporary listeners, due to their comparatively longer exposure to classical tonal music rather than to Renaissance modal music (e.g., Sears, Caplin, & McAdams, 2014). This is examined in the perceptual experiments below.

Applying the proposed conceptual blending system (see next section) to the perfect and Phrygian input spaces, the tritone substitution progression (see Figure 1) emerges; this cadence is highly ranked by the proposed blending process as it incorporates most of the salient features of both cadences (it includes both the most salient upward and downward leading notes). It is worth noting that the computational system "invents" this cadential type, which emerged in jazz, centuries after the main tonal/modal input cadences. On the other hand, a cadence that does not include any of these two properties, such as the backdoor progression (also used in jazz), may also appear as a blend (depending on how blends are rated/selected), but much lower in the ranking. Many other blends are possible, seven of which are further examined empirically.

Given that our computational system is capable of inventing novel cadential schemata by blending basic cadences, we are particularly interested in the following questions: Are the novel cadences generated by the system perceived as being single-scope blends (i.e., closer to one of the input cadences) or are they balanced double-scope blends (in-between the perfect and Phrygian cadences)? Are the generated highly ranked new cadences perceived by listeners as being successful blends between the perfect and Phrygian cadences (in case of double-scope blends) or as being interesting new versions of the perfect or Phrygian cadences (in case of single-scope blends)? How do listeners perceive the new cadences in terms of originality, expectancy, sense of closure, and tension? Which cadences do they prefer? The current study attempts to address these issues through a series of subjective experiments. It gives no definitive answers, but hopefully the descriptions, experiments, and

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[2] Also, sometimes the third of the Phrygian mode is omitted or raised in Renaissance modal cadences, especially when the cadence is the final one in the piece (Schubert 2008, p. 257, Ex. 17-9d). In spite of this practice, we have kept the final chord minor (with natural third degree) in our model, because we opted for maximum differentiation only at the penultimate chord of the cadential chord progression and not at the final chord, which is kept stable. This choice corresponds to the generic Phrygian cadence sequence and not to the final one.

discussions below will shed some light into perceptual aspects of musical creativity, opening the way for more extensive and thorough studies in the future.

All of the above questions are essentially related to the assessment of the system's creative capability. Evaluating creativity—either human or computational—is a non-trivial task, especially when the assessment of aesthetic quality is also involved. The matter is further complicated by the fact that the mere definition of creativity is problematic and not commonly accepted as many authors approach it from different perspectives (e.g., Boden, 2004; Wiggins, 2006; for a comprehensive discussion, see Jordanous, 2012, Chapter 3). As a result, creativity is often broken down into partial constituent dimensions (e.g., novelty, value, surprise, problem solving ability, originality, divergence, etc.) (e.g., Jordanous, 2012; Maher, Brady, & Fisher, 2013). In terms of assessing a creative system, the two usual approaches are either to directly evaluate the product of the system or to evaluate the production mechanism (Pearce & Wiggins, 2001). The former can be also viewed as a summative evaluation (Jordanous, 2012, Chapter 1) whereby the overall creativity of a system is sought for. The latter is a formative evaluation process whose objective is to provide evaluation feedback concerning certain attributes of the creative system during the development stage and, thus, direct possible improvements. The present work adopts essentially the summative approach (evaluation of the end products of the system), but also takes into account the formative characteristics of the creative system with a view to increasing its creative potential.

The empirical evaluation was performed by means of two subjective tests: a main nonverbal dissimilarity rating listening test (following a preliminary study reported in Zacharakis, Kaliakatsos-Papakostas, & Cambouropoulos, 2015) and a complementary verbal subjective test. Only musically trained participants were recruited for these experiments in order to minimize possible "noise" in the responses as a result of a potentially less common understanding of some musical concepts among nonmusicians. However, a future comparison of these results with corresponding data from nonmusicians might also prove informative. In the main experiment we opted for a (nonverbal) pairwise dissimilarity rating listening test between nine cadences (the two originals and seven blends). We subsequently applied multidimensional scaling (MDS) analysis to the acquired data and used the produced spatial configuration as an indirect way to measure the relation of blends to the input cadences. One intuitive assumption is that an "ideal" double-scope blend should be "equally" similar to each of the input cadences (it should resemble both input concepts) and therefore should appear between them (ideally near the middle) in such a spatial configuration, while weaker single-scope blends should be positioned closer to either of the originals (off the middle).

In a complementary experiment, a descriptive type of subjective evaluation (Verbal Attribute Magnitude Estimation) was employed to assess qualities of the produced blends that could contribute towards a better explanation of the MDS spatial configuration. In this experiment, the nine cadences were presented to listeners in two different harmonic contexts; namely, a tonal minor context and a Phrygian context, resulting in 18 cadential stimuli. Listeners were asked to rate each cadence according to preference, degree of tension, closure effect, originality, expectancy, and fit within the corresponding tonal/modal context. Originality, which is a key term for creativity evaluation (Hekkert, Snelders, & Wieringen, 2003; Jordanous, 2012), may also be seen as an equivalent to surprise and novelty or the opposite of expectancy, all of which have proven very important for music perception and appreciation (Huron, 2006). The alternation between tension and relaxation is regarded as one of the key factors for musically induced emotions and has been associated with the building of expectations or the difficulty to form any (e.g., Farbood, 2012; Huron, 2006; Krumhansl, 2015; Lehne & Koelsch, 2015; Lerdahl & Krumhansl, 2007). Closure effect is a specific characteristic of musical cadences (e.g., Sears et al., 2014) as cadences serve the purpose of concluding phrases, sections, or pieces of music. This sense of closure usually coexists with an increase of expectation as the cadential ending is approached (Huron, 2006, Rohrmeier & Neuwirth, 2015). Asking for the "goodness of fit" is appropriate when examining the perception of a tone within a given context and has been introduced as the "probe tone method" by Krumhansl and Shepard (1979). In our case, it is not a mere tone but a pair of chords that act as a cadential sequence and whose degree of fit with the preceding harmonic context is requested. Finally, preference simply measures the extent to which participants may prefer some cadences to others. Based on the previous, it would be expected that some of the examined descriptive attributes might convey a considerable amount of common information. Therefore, this work will aim to identify possible differences or similarities between them. More importantly, however, it will attempt to directly evaluate certain aspects of the creative blending system by also considering a possible effect of harmonic context on the cadential qualities characterizing a number of blends.

In the first section below, a systematic description of the conceptual blending mechanism is presented along with a formal representation of cadences. The next two sections present and discuss the two empirical experiments. An overall discussion of the findings concludes the paper.

A Computational Method for Conceptual Blending: Inventing New Cadences

The intended goal of a computational system for conceptual blending is to achieve a combination of different structural parts of two input conceptual spaces so that the generated blended space encompasses new structure and novel properties, preserving at the same time the common parts of the inputs. In computational creativity, conceptual blending has been modeled by Goguen (2006) as a generative mechanism, according to which input spaces are modeled as *algebraic specifications* and a blend is computed (this blend is referred to as a *colimit* in category theory (Awodey, 2010). A computational framework that extends Goguen's approach has been developed in the context of the COINVENT project (Schorlemmer et al., 2014) based on the notion of *amalgams* (Ontañón & Plaza, 2010, 2012). According to this framework, *input spaces* are described as sets of *properties,* and an *amalgam-based* workflow (Eppe et al., 2015) finds the blends by generalizing (or removing) input properties until a *generic space* (i.e., the set of common properties between the input spaces) is found; intermediate generalized versions of the input spaces are "merged" to create blends that are consistent or satisfy certain properties related to the knowledge domain (see Figure 2). At this point, it should be noted that in the process of blending through amalgams, the notions of "amalgam" and "blend" are essentially the same; therefore, in the following paragraphs they are used interchangeably.

In this paper the specific case of blending the perfect and Phrygian cadences discussed above is examined. For simplicity, we assume that each cadence consists of two chords, the second of which is always a C minor chord; only the penultimate chord can be altered through blending. The properties that are used for describing a cadence concern either its penultimate chord or pitch class differences/intervals between the two constituent chords (described later in Table 1). When blending two cadences, the amalgam-based algorithm first computes their generic space (common properties illustrated as point 1 in Figure 2). After the generic space is determined for two given input cadences, the amalgam-based process attempts to compute their *amalgam*, which is the *unification* of their content. If the resulting amalgam is inconsistent, then it iteratively generalizes the properties of the inputs (point 2 in Figure 2), until the resulting unification is consistent (point 3 in Figure 2). For instance, trying to directly unify the transitions I_1: G7 → Cm and I_2: B♭m → Cm would yield an inconsistent amalgam, since a transition cannot both include and *not* include a leading note to the tonic (which are properties of I_1 and I_2 respectively). Therefore, the amalgam-based process generalizes the property value that creates the clash in one of the inputs (e.g., the property describing the absence of leading note would be left empty in I_2) and tries to unify the generalized versions of the inputs again. It should be noted here that the cadences follow a feature term representation (Plaza, 1995) with no nested properties and, therefore, generalizing a feature value is done by leaving the property described by this feature empty.

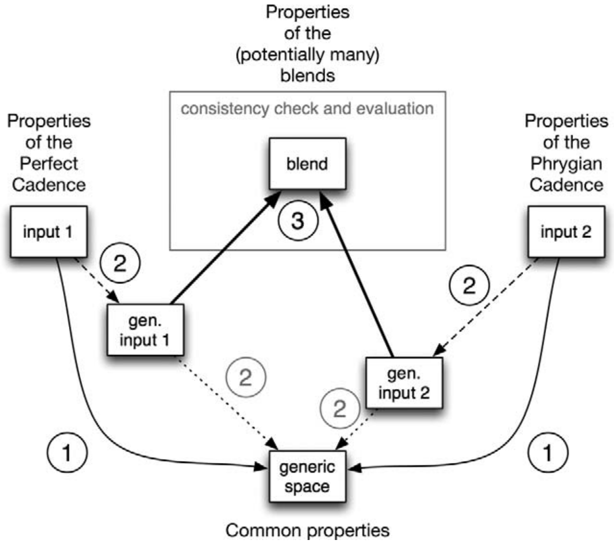

FIGURE 2. The conceptual blending scheme: properties describing the perfect and the renaissance Phrygian cadences are blended to create new cadences with combined properties. The generic space is computed (1) and the input spaces are successively generalized (2), while new blends are constantly created (3). Some blends might be inconsistent or evaluated poorly according to blending optimality principles or domain specific criteria.

After a number of generalization steps are applied (point 2 in Figure 2), the input spaces are generalized "enough" so that the resulting blend is consistent (point 3 in Figure 2). It may be the case, however, that the blend is *not complete*, in the sense that this process may have generated an overgeneralized result by overgeneralizing the inputs during the amalgamation step (e.g., in the case of cadence blending, the generated cadences may include chords with missing elements). Such blends are then completed by *blending completion* (Fauconnier & Turner, 2003), which is a domain-specific process that uses background knowledge to consistently assign specific property values to generalized terms. For instance, in the hitherto examined case, blend completion is used for completing the A♭ note (which does not exist in any input) as the fifth of the penultimate chord when obtaining the tritone substitution cadence (Figure 1). The overgeneralized term produced by amalgamation in the tritone substitution cadence example is a cadence with a penultimate major chord with minor seventh (dominant seventh type) and with a D♭ root. According to this type, a perfect fifth is assumed which, however, is missing since there is no A♭ in the inputs to be inherited during amalgamation. Completion is an automated process that extends the creative capabilities of the system since unforeseen elements may potentially emerge (as the A♭ note in the tritone example) that are grounded on relations given by the background knowledge (e.g., the chord type). In the current version of the system, completion is a post-blending process that examines whether basic chord properties are satisfied, by trying to complete in a consistent manner the missing chord elements, namely root pitch class, type and included pitch classes, based on a given set of chord types given in the background knowledge. Incorporating input cadences or background knowledge with arbitrarily diverse chord characteristics would allow the creation of blends with arbitrarily diverse chord types.

A FORMAL DESCRIPTION OF CADENCES FOR GENERATIVE CONCEPTUAL BLENDING

A cadence is described by several properties that concern both the penultimate chord and musical values that change during its transition to the final chord. These properties along with the property values for the perfect cadence are shown in Table 1. Among the properties that are included in the description of the penultimate chord are its root and type; chord roots are necessary for computing the root difference with the final chord. For computing the root and type in a consistent manner for all utilized chords, the *General Chord Type (GCT)* representation (Cambouropoulos, Kaliakatsos-Papakostas, & Tsougras, 2014) has been employed, which allows the rearrangement of the notes of a harmonic simultaneity such that abstract types of chords along with their root may be derived. This encoding is inspired by the standard Roman numeral chord type labeling, but is more general and flexible since it can be used to describe chords in any musical idiom. The GCT algorithm finds the maximal subset of notes in a simultaneity that contains only consonant intervals, given a user-defined consonance-dissonance classification of intervals that reflects sensory and/or culturally dependent notions of consonance/dissonance. This maximal subset forms the *base* upon which the chord type is built, while the lowest note of the base is the *root* of the chord. Any remaining notes that cannot be a part of the maximally consonant subset are included in the *extension* of the GCT type. For example, by considering the unison, third/sixth and perfect fourth/fifth intervals as consonant, the GCT representation of the first degree (I) chord in a major scale is [0, [0 4 7]], where 0 indicates the root note in relation to the scale (0 is the scale's first degree) and [0 4 7] is the chord's type (4 indicates a major third and 7 a perfect fifth). Accordingly, a V7 chord is denoted by [7, [0 4 7], [10]], where 10 is the extension (minor seventh), which cannot be included in the base considering that the tritone and minor seventh intervals are dissonant. As the GCT representation is general and can be applied to

TABLE 1. *Properties Describing a Cadence - An Example of the Perfect Cadence (Ending in C minor)*

Index	Property name	Description	Value
1	*fcRoot*	Root of the penultimate chord (numeric value)	7
2	*fcType*	Type of the penultimate chord (GCT type)	[0 4 7 10]
3	*fcPCs*	Pitch classes of the penultimate chord	{7 11 2 5}
4	*rootDiff*	Root difference for the transition	5
5	*DIChas0*	Existence of common pitch class between the two chords, i.e. zero pitch interval transition (Boolean value)	1
6	*DIChas1*	Existence of upward semitone movement between any pitch classes of the two chords (Boolean value)	1
7	*DIChasN1*	Existence of downward semitone movement between any pitch classes of the two chords (Boolean value)	1
8	*hasAscSemiToZero*	Existence of ascending semitone to the tonic, i.e. upward leading note (Boolean value)	1
9	*hasDescSemiToZero*	Existence of descending semitone to the tonic, i.e. downward leading note (Boolean value)	0
10	*hasSemiToZero*	Existence of upward or downward semitone movement to the tonic (Boolean value)	1
11	*hasAscToneToZero*	Existence of ascending whole step (tone) to the tonic, i.e. upward leading note (Boolean value)	0

non-standard tonal systems such as modal harmony and, even, atonal harmony, the blending scheme considered for the cadences described herein, can be generalized to cadences of practically any musical idiom.

Cadence properties 1-3 (Table 1) describe the first (penultimate) chord of the cadence; the first two properties (chord root and type) are computed by the GCT algorithm. The pitch classes of the chord are described in Property 3. Property 4, which is the difference between the chord roots, is an integer between −5 and 6 that indicates the pitch class difference between the roots of the first and second chords of the cadence. Property 5 captures the existence of a common pitch class between the two chords, while properties 6 and 7 indicate the existence of a semitone movement (upward and downward respectively) in any pitch class of the cadence transition. Properties 5, 6, and 7 actually indicate if there is a 0, 1 or −1 in the Directional Interval Class (DIC) (Cambouropoulos, 2012; Cambouropoulos, Katsiavalos, & Tsougras, 2013), flagging whether there are small pitch class voice leading movements (repeating notes or semitone movements) in the cadence. Properties 8 to 10 are used to indicate whether there exists a semitone movement (property 10) to the tonic from the first to the second chord of the cadence, as well as whether this movement is ascending (property 8) or descending (property 9); these properties reflect the importance of the leading note (upwards or, even, downwards). Property 11 indicates whether an ascending whole step (tone) movement to the root of the tonic chord is included in the cadence.

GENERATING, REJECTING, AND RANKING BLENDS

Table 2 illustrates a blending example, where the tritone substitution cadence is created from the perfect and the Phrygian cadences. This blend incorporates property values from both input spaces, many of which are common to both spaces, while new values have also been added through completion. Specifically, this blend includes four property values exclusively from input 1 (*fcType* [0 4 7 10], *fcPCs* 11, *DIChas1* 1, *hasAscSemiToZero* 1, *hasAscToneToZero* 0), three values exclusively from input 2 (*fcPCs* 1, *DIChas0* 0, *hasDescSemiToZero* 1), three common values (*fcPCs* 5, *DIChasN1* 1, *hasSemiToZero* 1) and three new property values that were not present in any input space (*fcRoot* 1, *fcPCs* 8, *rootDiff* 1). Therefore, the property values of the blended space come from either input space, or are completed by logical deduction through axioms describing cadences (e.g., the pitch class 8 was added as a *fcPCs* property value, functioning as a fifth of the new chord), as indicated in the parentheses next to each respective property.

By blending through the amalgamation process, the generation of several blends from two input spaces is allowed. In a strict sense, a cadence that does not include a common property value of the two inputs (i.e., that does not satisfy the generic space restrictions) should not be considered as their blend. The notion of the generic space in the conceptual blending theory is an abstract space that incorporates generic attributes of the input spaces (see Fauconnier & Turner, 2003). To some extent this notion is related with the idea of induced schemas (Gick & Holyoak, 1983), which are abstract objects describing general attributes and relations in human perception and cognition. However, research advancements on utilizing generic elements like image schemas for forming the generic space are very recent and currently examined only on a theoretical level (Hedblom, Kutz, & Neuhaus, 2016). On the other hand, since the role of the presented blending framework is generative and not interpretative, new spaces

TABLE 2. *Example of the Tritone Substitution Cadence Invention, by Blending the Perfect and the Phrygian Cadences*

Property's name	Input 1 (perfect)	Input 2 (Phrygian)	Possible blend	salience
fcRoot	7	10	1 (new)	1
fcType	[0 4 7 10]	[0 3 7]	[0 4 7 10] (input 1)	1
fcPCs	[7 11 2 **5**]	[10 1 **5**]	[11 1 5 8] (combination and new)	[2,1,2,1]
rootDiff	5	2	1 (new)	1
DIChas0	1	0	0 (input 2)	1
DIChas1	1	0	1 (input 1)	1
DIChasN1	**1**	**1**	**1** (both)	1
hasAscSemiToZero	1	0	1 (input 1)	3
hasDescSemiToZero	0	1	1 (input 2)	3
hasSemiToZero	**1**	**1**	**1** (both)	3
hasAscToneToZero	0	1	0 (input 1)	1
			Total salience:	22

Note: Generic space elements (common properties of inputs) are shown in bold. The assignment of salience values is explained in the text.

need to emerge by obtaining specific elements from the inputs and, therefore, it is required that specific elements are also included in the modeling of the input spaces. The inclusion of such elements in the generic space, as is the case with the COINVENT blending framework, often deteriorates the creative capabilities of the system by imposing strict restrictions that in some cases do not allow the emergence of interesting blends. For instance, the "backdoor progression" cadence in jazz, B♭7 → Cm, would not be produced if generic space restrictions are adhered to, since it does not have a semitone movement to the tonic's root, which is a common property of both inputs (*hasSemiToZero* 1). This cadence, failing to satisfy a generic space property value as well as many others, would never be produced by the strict version of the presented methodology.

In this study, we considered it important to allow diverse cadences that could potentially be considered as blends, even if they incorporated few of the input property values and regardless of whether these values should normally comply with generic space restrictions. For enabling the generation of several diverse blends, the restrictions imposed by the generic space are *not* considered in the amalgamation process. In the strict version of the system, cadences 4, 6, and 7, as presented in the Materials section, would not have been produced by the system if the role of the generic space was strictly considered for all structural elements, since their penultimate chords do not have a pitch class with semitone movement (up or down) to the tonic. Additionally, acceptable cadence blends are the ones whose penultimate chord conforms to a specified dictionary of chord types (domain-specific knowledge). The chord type dictionary includes some standard chords in tonal music (1-5) as well as two types that allow a wider diversity in the blends:

1. [0, 4, 7] (major),
2. [0, 3, 7] (minor),
3. [0, 4 ,7, 10] (major with minor seventh),
4. [0, 3, 7, 10] (minor with minor seventh),
5. [0, 3, 6] (diminished),
6. [0, 3, 6, 10] (half diminished) and
7. [0, 4, 6, 10] (major with minor seventh and lowered fifth).

In conceptual blending, after all blends have been generated, an evaluation process ranks them according to certain optimality principles (Fauconnier & Turner, 2003); a complete description is outside the scope of this paper and the reader is referred to Goguen and Harrel (2010) for the application of such principles to the Alloy algorithm. An important aspect for defining meaningful combinations of different concepts is the ability to discriminate between salient and non-salient features (Goel, 2014). We believe that for a blend to retain the character of the objects/spaces being blended, features that are more characteristic of each object/space should be included in the blend. Blending optimality in the paper at hand is tackled through the assignment of salience weights for certain values of properties (e.g., the property rootDiff in a cadence could have a value 5 corresponding to a fourth/fifth interval root relation, which might be considered important in relation to other values in other cadences), which indicate the importance of specific features in cadences. More specifically, we assume that there are three grades of salience, expressed as numerical weight values on a scale from 1 to 3 indicating non-salient (value 1), relatively salient (value 2), and highly salient (value 3) features.

The weight value of each feature of the cadential progressions is assigned by hand according to basic musicological assumptions on the salience of features. The question arises: which are the characteristic attributes (property values) of the perfect and Phrygian cadence sequences? Ideally, such salience weights should be extracted via corpus-driven statistical analysis or by empirical research. In our case, we use musicological knowledge/intuition. We assume that, for the perfect cadential sequence, the leading note in the dominant chord—more generally seen as a dominant (D) function in functional harmony—is the most important feature as it cannot be omitted in 3- or 4-part harmony. The root of the dominant is considered somewhat less important since it can be omitted, as in the case where the diminished vii6 chord plays the role of the dominant (this progression actually occurs in several Bach chorale phrases, and theorists tend to assign cadential role to this progression, e.g., Lerdahl & Jackendoff (1983, p. 158). Furthermore, other theorists like Ratner and Meyer have considered cadential progressions with the V7 in inversion (e.g., V6/5 or V4/2), dismissing the necessity of the perfect fourth/fifth bass leap. (Caplin, 2004, p. 67-69, also acknowledges these cases, although he finally disagrees with this concept.) Additionally, the B-F tritone (in C major) is relatively important as it is very characteristic of the dominant seventh chord, implying specific resolution and voice-leading movement (it is not considered highly salient, as the dominant may appear without the seventh, retaining its dominant function in the perfect cadence). For the Phrygian cadential sequence, we assume that the downward leading note is the most important feature as it is the most distinctive feature of the Phrygian mode and is diametrically different in relation to the perfect cadence in the major-minor tonal framework. Of course, other music theorical approaches may give different weightings of properties, in which case a different ranking of the (same) blends would appear.

According to the aforementioned remarks, for the perfect cadence, the salience weights for specific property values are the following:

1. Leading note to the tonic is most important (weight value 3 for the hasAscSemiToZero feature and for the hasSemiToZero properties).
2. The fifth relation of the root of the dominant to the root of the tonic is relatively important (weight value 2 for the for a value 5 for the *rootDiff* property).
3. The F-B tritone is relatively important. (Weight value 2 for the fcPC properties 5 and 11 only in the case where they are both included. If only one of them is included, it is given a weight value of 1.)

For the Phrygian cadence, the only assumed important feature is the downward leading note (weight value 3 for a 1 value of the hasDescSemiToZero property), since it is very characteristic of the Phrygian mode, especially when considered in comparison to the perfect cadence in tonal music. The upward whole step movement of the root of the semifinal chord to the root of the final tonic may also be considered relatively important (weight value 2 for a 1 value 1 of the hasAscToneTo Zero property). All other properties in both input spaces are considered less salient and are thus assigned a weight value of 1.

When a blend inherits a property value from an input, it is also considered to inherit its salience. The basic assumption in this paper is that blends that are ranked higher should incorporate as many of the most salient input features as possible, since this will promote the generation of blends that incorporate a stronger perceptual correlation with the characteristics of both of the inputs and of the spaces that these inputs have been taken from. Thus, the ranking of blends is based on the total salience (final row of Table 2), which is expressed as the sum of the feature weights it inherits from the inputs. In the case where a property value is not inherited from the inputs but is generated through completion, it is assigned the default salience weight value 1.

MATERIALS

The computer system that implements the blending setup described above produced 84 blended cadences, all of which had some relation to both or either of the inputs. The inclusion of all 84 blends in an empirical experiment is practically unfeasible (especially for a pairwise dissimilarity rating setup). Therefore, a selection of a representative subset for inclusion in the stimulus set had to be made. To this end, seven blends reflecting different levels of ranking were chosen, in an effort to attain a maximally diverse test corpus. As stated previously, all cadences (that were assumed to be in C minor tonality/modality) consisted of two chords, the penultimate/dominant and the final/tonic. The final chord was kept constant (C minor), thus variation between the stimuli resulted from altering the penultimate chords. Also, maximum uniformity in the formation of the chords and in voice-leading was pursued: all cadences were rendered with manual (human-made) voice-leading in four-voice harmony, with the upper voice moving upwards to the tonic (^7 - ^8, where possible), and with minimal movement in the inner voices. Figure 3 depicts the nine cadential pairs of chords, described from a music-theoretical perspective, in the following list:

1. Perfect cadence, featuring the full V^7 dominant chord that resolves to the i tonic chord without fifth, in order to achieve correct voice leading. This cadence involves a functional chord progression (chords moving downwards in the circle of perfect fifths) and strong voice-leading elements (the leading note resolving upwards to the tonic and the seventh of the dominant resolving downwards to the third of the tonic, with the two active voices forming a tritone: F-B).
2. Phrygian cadence, with the ♭vii chord in first inversion resolving to the i tonic chord. This cadence is considered contrapuntal, as it is based on a pair of linear steps (the downward leading note D♭ in the lower voice resolving by a semitone to the tonic and the B♭ in the upper voice moving upwards by a whole-tone to the tonic) and involves chord root movement by an ascending second (B♭ to C).
3. Tritone substitution progression, with the $\flat II^{7\flat}$ chord (German-type augmented sixth chord) leading to the tonic. The chord can also be considered an altered vii^{o7} with its lowered third in the lower voice. The progression incorporates elements from the two source cadences, as it includes both leading notes (upward leading note in the upper voice and downward leading note in the lower voice), includes the tritone F-B, and implies a functional dominant-to-tonic relation.
4. Backdoor progression, with the $\flat VII^7$ chord in first inversion, in order to achieve maximum voice-leading uniformity. This progression is mainly contrapuntal and similar to the Phrygian, but without the downward semitonal leading note, while the D in the third voice can be considered

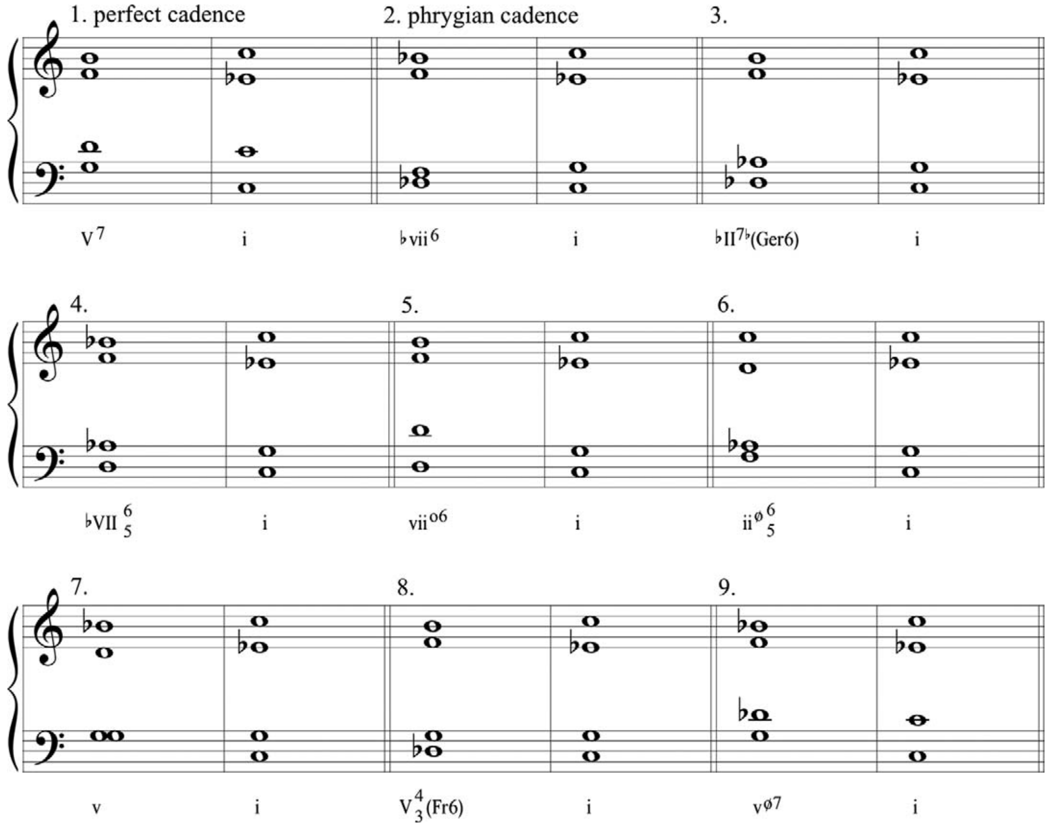

FIGURE 3. Score annotation of the nine cadences that constituted the stimulus set.

a borrowed element from the perfect cadence. Also, the penultimate chord is of the same type as in the perfect cadence (major triad with minor seventh) and includes a different tritone (D-A♭), implying a functional progression in E♭ major tonality.

5. Contrapuntal-type tonal cadence, with the vii^{o6} resolving to the minor tonic. The vii^{o} is considered to have a dominant function, i.e., V^7 without its root, and it has an upward leading note in the upper voice. The removal of the downward perfect fifth in the lower voice and its substitution by a downward step (D-C) can be considered an interesting affinity with the outer voices of the Phrygian cadence.
6. Plagal-type cadence, with the $\text{ii}^{o6/5}$ progressing to the tonic. The $\text{ii}^{o6/5}$ is considered also a subdominant chord with added sixth (iv^{add6}), and there is no leading note in any of the voices. The progression also features a downward perfect fourth leap in the lower voice, typical of subdominant to tonic progressions. This progression can thus be considered distantly akin to the input cadences due to certain common chordal tones (D, F), the inclusion of a tritone (D-A♭) and similar voice-leading (D-E♭, A♭-G).
7. Minor-dominant to minor-tonic progression, utilizing chords from the natural minor scale (Aeolian mode). This modal progression does not include leading tones. It can be considered closer to the perfect cadence due to the perfect fifth relation of the chord roots, but the lack of semitonal resolution in the upper voice and of the tritone can also be considered reciprocal elements of the Phrygian cadence.
8. Altered dominant seventh chord to minor-tonic progression, with the dominant in second inversion and with its fifth lowered (French-type augmented sixth chord). This chromatic linear progression was used in the second half of the 19th century and features two leading notes, one upward in the upper voice and one downward in the lower voice. This progression is similar to No. 3, and can also be considered closely related to both source cadences, as it incorporates both leading notes, and includes the tritone F-B and a functional dominant-to-tonic relation.

TABLE 3. *The Penultimate Cadence Chords and Respective Indexes and Ranking According to Total Sum of Property Salience Weights (Total Salience)*

	input		blends						
index	1	2	3	4	5	6	7	8	9
pitch classes	[7 11 2 5]	[10 1 5]	[1 5 8 11]	[10 2 5 8]	[11 2 5]	[2 5 9 0]	[7 10 2]	[1 5 7 11]	[7 10 1 5]
chord type	[0 4 7 10]	[0 3 7]	[0 4 7 10]	[0 4 7 10]	[0 3 6]	[0 3 7 10]	[0 3 7]	[0 4 6 10]	[0 3 6 10]
Total salience	–	–	22	15	19	14	15	23	20
System ranking	–	–	2-3	47-56	12-19	57-51	47-56	1	5-11

Note: Cadences belonging to the ranking positions 1-19 (in bold) are the cadences produced by the system when considering the generic space restrictions in the blending process.

9. Half-diminished "dominant" seventh chord to minor-tonic progression. This synthetic chord progression has not actually been used in any tonal or modal harmonic idiom, but it has been included in the experiment, since it incorporates key elements from input cadences (fifth root relation, downward leading note in inner voice resolving to the tonic). Despite the perfect fifth root relation, the progression cannot be considered functional (dominant-to-tonic type), and is distantly related to cadence no. 5, since the penultimate chords are of the same type (half-diminished seventh chords).

Table 3 shows the features of the penultimate chords in the GCT format. The ranking of the 7 selected blends based on the ranking scheme described previously is illustrated in the final row of the table; the selection includes high as well as low-ranked cadences.

Experiment 1

METHOD

The first experiment aimed to investigate relative perception within the set of the generated cadences. A pairwise dissimilarity listening test was deemed appropriate for this purpose, as the dissimilarity matrices it produces allow Multidimensional Scaling (MDS) analysis to generate geometric configurations that represent the relationships between percepts. This in turn enables the interpretation of salient perceptual dimensions.

In the pairwise dissimilarity listening test, participants were asked to compare all pairs among the 9 cadences described in the previous section using the free magnitude estimation method. Therefore, they rated the perceptual distances of 45 pairs (same pairs included) by freely typing in a number of their choice to represent dissimilarity of each pair (i.e., an unbounded scale) with 0 indicating a same pair (for a discussion of the advantages of this approach over a bounded magnitude estimation see Zacharakis, Pastiadis, & Reiss, 2015). The stimuli were exported as .wav files from the music annotation software Finale using piano as a playback instrument. Each stimulus lasted around 4 s and interstimulus interval was set at 0.5 s. The listening test was conducted under controlled conditions in acoustically isolated listening rooms. Sound stimuli were presented through the use of a laptop computer, with an M-Audio (Fast Track Pro USB) external audio interface and a pair of PreSonus HD7 circumaural headphones.

For the analysis of dissimilarity data between the examined cadences, this work employed a non-metric (ordinal) weighted (INDSCAL) MDS approach as offered by the SPSS PROXSCAL (proximity scaling) algorithm (Meulman & Heiser, 2008). PROXSCAL applies an ordinal (rank order) transformation to the raw dissimilarities within each participant's responses, thus addressing the issue of the different rating scales used as a result of the free magnitude estimation approach. In turn, INDSCAL computes weights that represent the importance attributed to each perceptual dimension by each participant and then uses these weights to reconstruct an "average" perceptual space.

The interpretation of the spatial configuration that was obtained through MDS was attempted through combination of one sensory and one cognitive model in a similar manner to (Bigand, Parncutt, & Lerdahl, 1996). To this end, the auditory roughness of the penultimate chords was calculated by the use of Vassilakis' algorithm as implemented in the MIR Toobox (Lartillot & Toiviainen, 2007) while the cognitive difference between the chords within each pair was calculated according to the Tonal Pitch Space (TPS) model (Lerdahl, 2001). Roughness calculation was based on the summation of roughness between all pairs of sinusoids that were obtained through spectral peak-picking (Vassilakis, 2001, Eq. 6.23). The calculation of distances according to the TPS was performed with the use of the *chord distance rule* (Lerdahl, 2001, p. 60). The chord distance value yielded depends on the distance between diatonic collections, on the chordal roots' distance in the circle of fifths and on the number of non-common tones.

Participants. Twenty listeners (age range = 18-44, mean age = 24.9, 10 male) participated in the first listening experiment. Participants were students of the School of Music Studies at the Aristotle University of Thessaloniki. All of them reported normal hearing and long-term music practice (16.5 years on average, ranging from 5 to 35). All participants provided informed consent and were naive about the purpose of the test. This experiment was certified for ethical compliance by the review ethics board of the Aristotle University of Thessaloniki.

Procedure. Listeners became familiar with the range of cadences under study during an initial presentation of the stimulus set (random order). This was followed by a brief training stage where listeners rated the distance between four selected pairs of cadences. For the main part of the experiment participants were allowed to listen to each pair of cadences as many times as needed prior to submitting their dissimilarity rating. The pairs were presented in random order and participants were advised to retain a consistent rating strategy throughout the experiment. In total, the listening test sessions, including instructions and breaks, lasted around thirty minutes for most of the participants.

RESULTS

Before proceeding to the main body of the analysis for the dissimilarity data, we examined the internal consistency of the dissimilarity ratings. Cronbach's alpha was .94 indicating high interparticipant reliability.

In the main body of the analysis, the dissimilarity ratings were analyzed through MDS as described above. Table 4 shows two measures of fit along with their improvement for each added dimension. Lower S-Stress values (with a minimum of 0) represent a better fit, in contrast to Dispersion Accounted For (D.A.F.) where a better fit is indicated by higher values (with a maximum of 1). A two-dimensional solution was deemed optimal for data representation as the improvement of both measures when adding a third dimension was minimal. Figure 4 shows the configuration of the cadences within this 2-D space.

Simple visual inspection of Figure 4 can reveal some parameters that seem to have influenced the perception of the different cadences. The first dimension of the space can be interpreted as "tonal" vs. "modal" based on the fact that all cadences featuring a leading note resolving to the tonic (upward semitone movement from B to C) cluster at the negative side while all cadences featuring an upward tone movement (B♭ to C) cluster at the positive side. The plagal cadence (No. 6) that features a duplication of the tonic is positioned almost exactly in the middle of the first dimension. The interpretation of the configuration along the second dimension, however, is not so obvious. It could be that a combination of the inherent dissonance of the penultimate chord (as reflected by its type and voicing layout) together with its distance from the final chord in the Tonal Pitch Space theoretical/cognitive model (Lerdahl, 2001) may explain the positions along this dimension. This notion resembles the breaking of dissonance in static "sensory dissonance" and dynamic "tension dissonance" suggested by Huron (2006, Chapter 15, p. 311). Indeed, distances in the Tonal Pitch Space (TPS) in combination with the roughness (i.e., sensory dissonance) of each penultimate chord calculated using the Vassilakis' algorithm—as calculated by the MIR Toolbox (Lartillot & Toiviainen, 2007)—seem to account for the ordering of cadences along the second dimension. Table 5 shows the

TABLE 4. *Measures-of-fit and their Improvement for Different MDS Dimensionalities*

Dimensionality	Stress I	Improvement	D.A.F.	Improvement
1D	.36	—	.87	—
2D	.20	.16	.96	.09
3D	.13	.07	.98	.02

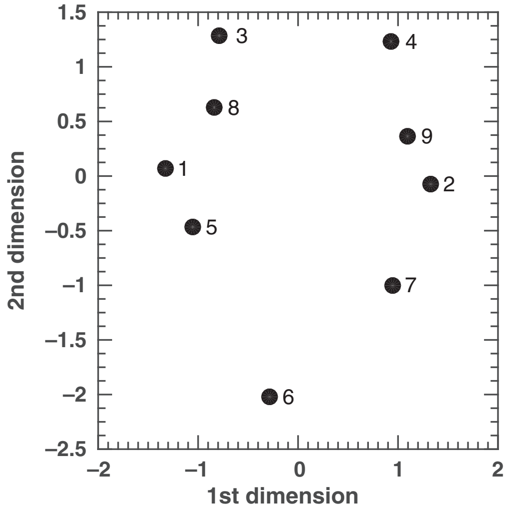

FIGURE 4. The two-dimensional dissimilarity perceptual space of the nine cadences. The perfect and the Phrygian cadences (No. 1 & 2) are positioned far away from each other on the first dimension.

TABLE 5. *Tonal Pitch Space Distance and Roughness Value of Each Penultimate Chord for Each Cadence*

	cadence index								
	1	2	3	4	5	6	7	8	9
Tonal Pitch Space distance	7	9	11	9	9	6	5	8	8
roughness (Vassilakis' algorithm)	4.20	5.60	4.13	5.11	3.06	5.05	3.16	5.25	5.13

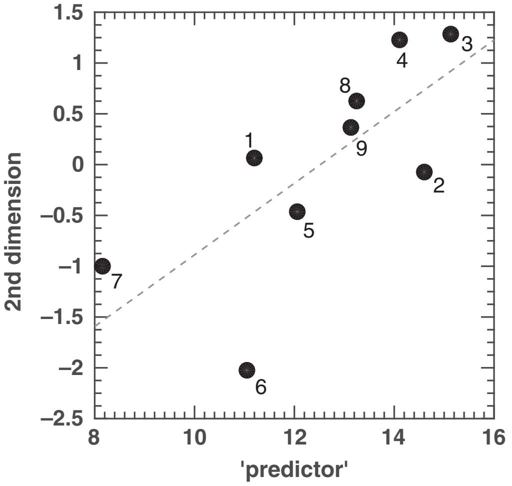

FIGURE 5. Scatter plot between the second perceptual dimension and the simple predictor: tonal pitch space distance + roughness value. The best-fit line corresponds to $\rho(8) = .78$ ($p < .05$).

chord distance values of each cadence according to the TPS model together with the roughness of the penultimate chord and Figure 5 shows the scatter plot between the second perceptual dimension against a simple predictor variable (TPS distance plus roughness value). The Spearman's correlation coefficient corresponding to this scatterplot is $\rho(8) = .78$, $p < .05$, indicating a strong relationship between this metric and the second MDS dimension. It has to be noted that the Spearman's correlation coefficients between each of these two components in isolation and the second dimension were nonsignificant. Furthermore, for a linear combination of the components, the Spearman's correlation was maximized by a mere summation.

DISCUSSION

The dissimilarity rating experiment suggests a categorical perception mode in the way cadences are perceived. This is reflected by the positioning along the first MDS dimension and seems to be dictated primarily by the existence of an upward semitone movement to the tonic (upward leading note) in the left-hand cadences in comparison to the lack of an upward leading note in the right-hand cadences. Two major clusters of cadences were formed based on this differentiation along with one outlier (the plagal cadence) that featured neither an upward semitone nor an upward tone to the tonic but a duplication of the tonic. The implications of categorical perception in the blending process will be discussed in the final general discussion.

The differentiation of cadences along the second MDS dimension was less obvious but could be explained to a great extent by the inherent dissonance of the penultimate chords (as expressed by the MIR Toolbox roughness calculation) together with their distances from the final chord in Lerdahl's Tonal Pitch Space. The combined influence of sensory (i.e., auditory roughness) and cognitive (i.e., Tonal Pitch Space distance) parameters has been suggested to account for the perceived tension in music (e.g., Bigand et al., 1996). The next experiment, which also includes tension among other descriptors of cadential closure, will serve to clarify whether the second MDS dimension could be indeed interpreted in terms of perceived tension.

Experiment 2

METHOD

The second experiment was designed as complementary to the first one. Pairwise dissimilarity ratings can be very useful for creating a spatial representation of the perceptual space. However, while being explicit regarding perceived similarity relationships of the objects under study, it may prove to be rather implicit when it comes to the interpretation of these relationships. Therefore, we designed a Verbal Attribute Magnitude Estimation (e.g., Kendall & Carterette, 1993a, 1993b) type of experiment whereby listeners rated the nine cadences on four descriptive scales: *preference*, *originality*, *tension* and *closure effect*.

After the analysis of the acquired data, an extension of this experiment was carried out. As will be explained in detail later, the ratings on originality were not very consistent across participants, implying that there was a lack of common understanding of this concept. Therefore, the same experimental protocol was repeated recruiting different participants and requesting a rating on merely two additional concepts that were regarded to be relevant to originality but at the same time more clearly defined: *expectancy* and *fit*.

The points of interest were multiple here. First, we wanted to see the level of agreement between raters regarding judgements upon these scales and also to examine the potential relationships between the scales. Additionally, we sought to investigate the effect that different harmonic contexts may have on the perception of these particular cadences as expressed by the ratings. And finally, we wanted to interpret these results in the light of the perceptual cadence space generated from Experiment 1 and vice versa.

Materials. Figure 6 presents the stimulus set that consisted of the nine cadences of Experiment 1 positioned in two different harmonic contexts (one tonal and one modal). Each stimulus comprises a four-bar phrase, with a two-bar antecedent sub-phrase and a two-bar consequent sub-phrase. The first two-bar sub-phrase suggests the harmonic content with a four-chord progression and has two versions: the tonal version (stimuli 1 −1 to 1-9) in C minor tonality and the modal version (stimuli 2 −1 to 2-9) in C Phrygian mode. The second two-bar sub-phrase contains the two-chord cadential progression in slower harmonic rhythm to strengthen the effect of phrase closure, and has nine versions (the cadences of experiment 1). An attempt was made to maximize both voice-leading uniformity and harmonic idiom specification. The former condition was achieved by the use of the same sequence of melodic degrees in the upper voice for almost all stimuli: ^3 - ^2 - ^1 - ^1 - ^7 - ^1 (except stimuli 1-6 and 2-6, which do not have ^7 melodic degrees). For the fulfillment of the latter condition, two four-chord progressions should be devised for each of the two versions of the first sub-phrase, containing the most characteristic elements of the two harmonic idioms. The sequence for the description of the minor tonal idiom was i - V^7 - VI - iv (emphasis on functional progressions, the dominant chord, and the sharpened leading note) and the sequence for the Phrygian mode was i - ♭vii - iv - i^6 (emphasis on the lowered ^2 degree and non-functional progressions). All stimuli were exported as .wav files from the music annotation software Finale using piano as a playback instrument and lasted around 9 s. The equipment and listening conditions were identical with Experiment 1.

Participants (group 1). Twenty six listeners (age range = 18-36, mean age = 22.7, 17 male), different from those who took part in the first experiment, participated in the first listening experiment. Participants were students from the School of Music Studies at the Aristotle University of Thessaloniki. All of them reported normal hearing and long term music practice (12.8 years on average, ranging from 6 to 25). All participants were naive about the purpose of the test.

Participants (group 2). A different group of twenty five listeners (age range = 20-50, mean age = 26.7, 15 male) participated in the second listening experiment. Participants were students from the School of Music Studies at the Aristotle University of Thessaloniki. All of them reported normal hearing and long term music practice (15 years on average, ranging from 5 to 40).

All participants (group 1 and 2) provided informed consent and were naive about the purpose of the test. This experiment was certified for ethical compliance by the review ethics board of the Aristotle University of Thessaloniki.

Procedure. Listeners became familiar with the type of stimuli through an initial random presentation of five examples. Then, the stimuli were presented within the two different harmonic contexts. Both the order of the harmonic context and the order of the cadences within each context were randomized. Participants were allowed to listen to each stimulus as many times as needed prior to submitting their rating on all provided scales. The strengths of the attributes were represented by sliders tagged with Greek attribute names (featuring also an English translation in parenthesis) whose endpoints were labeled "low" to "high," corresponding to a hidden numeric scale ranging from −10 to 10. In total, the listening test sessions, including instructions and breaks, lasted around twenty minutes for most of the participants.

Results. Before analyzing the data, we examined the internal consistency of responses for each rating scale for both harmonic contexts. Cronbach's alpha was .91 for preference, .77 for originality, .85 for tension, .94 for closure effect, .94 for expectancy, and .92 for fit. These results indicate excellent interparticipant reliability for *preference, closure effect, expectancy,* and *fit*. The consistency of *tension* is good, but *originality* features a significantly lower consistency. Based on this, originality will not be further examined since interpretation of its results is not considered reliable. Figure 7 presents the boxplots of each cadence for the five descriptive scales and the two harmonic contexts.

As ratings on several cadences did not pass the Shapiro-Wilk normality test ($p < .05$) a nonparametric approach was taken for examining the effect of harmonic context on cadence description. Wilcoxon Signed-rank

FIGURE 6. The score annotations of the stimulus set, which consisted of the nine cadences of Experiment 1 positioned in two different harmonic contexts: (a) tonal and (b) modal.

FIGURE 6. [Continued]

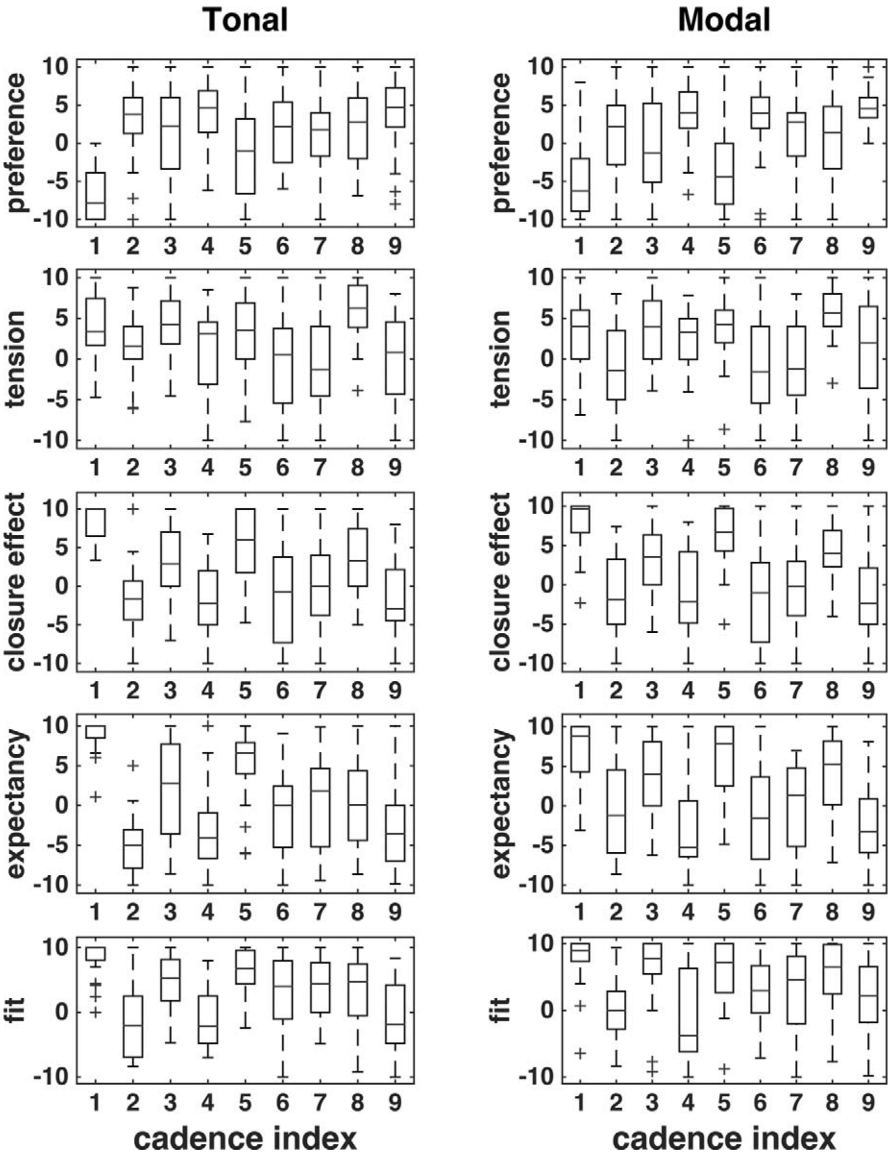

FIGURE 7. Boxplots of the nine cadences for the five descriptive scales and the two different harmonic contexts.

tests for each cadence revealed a harmonic context effect only for the expectancy ratings of the perfect (No. 1) Mdn_tonal $= 10$ vs. Mdn_modal $= 8.8$, $Z = 2.1$, $p < .05$, $r = .29$; phrygian (No. 2) Mdn_tonal $= -5$ vs. Mdn_modal $= -1.2$, $Z = -2.8$, $p < .05$, $r = -.40$; and French sixth (No. 8) Mdn_tonal $= .07$ vs. Mdn_modal $= 5.3$, $Z = -2.2$, $p < .05$, $r = -.31$. For all the other cadences and rating scales no effect of harmonic context was found. At this point, it has to be noted that the above effects were not corrected for multiple comparisons. If the level of significance was reduced to $p/5$ (taking into account the 5 different attributes) or even to the stricter $p/9$ (taking into account the 9 different cadences) according to a Bonferroni correction, then no effect would be identified. Obviously, this practice would increase the probability of falling into a type II error and rejecting an existing effect. Therefore, following the guidelines of Armstrong (2014) regarding the appropriate use of the Bonferroni correction, current results are reported at the significance level of $p < .05$. Furthermore, in the rating scale level, expectancy was the only scale that featured a significant effect of harmonic context indicating an overall increase in modal context, Mdn_tonal $= 0$ vs. Mdn_modal $= 2.4$, $Z = -2.35$, $p < .05$, $r = -.11$. Figure 8 shows the boxplot of all five rating scales aggregated for both harmonic contexts (although the

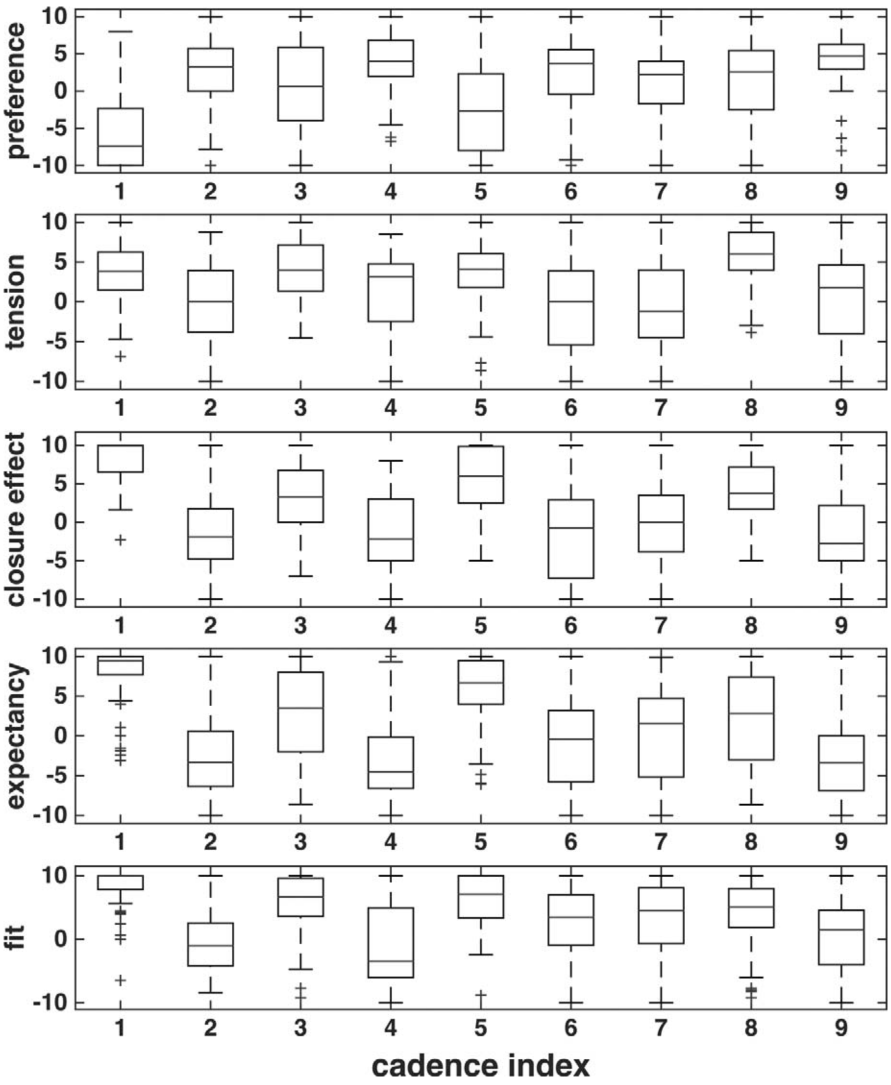

FIGURE 8. Boxplots of the aggregated data for the nine cadences on the five descriptive scales.

overall expectancy boxplots should be viewed having in mind that this scale exhibits an effect of harmonic context). Inspection of Figures 7 and 8 reveals that cadences that featured an upward leading note (No. 1, 3, 5, and 8) tended to receive higher ratings for closure effect and tension, and lower ratings for preference regardless of harmonic context. Thus, the positioning of cadences along dimension 1 of the perceptual space (Figure 4) is also reflected by the descriptive data. A Page's trend test showed a very strong trend (Page's L = 13494, z =117.28, $p < .001$) for increasing closure effect from the positive to the negative side of the first MDS dimension. This suggests that positioning of cadences along this dimension represents the perceived "strength" of closure signified by the cadence.

The interpretation of dimension 2 is not so straightforward. A visual inspection of the boxplots for overall tension implied that tension might play a role in positioning along dimension 2. To examine this hypothesis, we performed a Page's trend test that showed a significant trend for increasing tension along the second MDS dimension (Page's $L = 11749$, $z = 3.20$, $p < .001$). Strong trends were also present within the leading-note plus plagal cadence cluster (No. 6-5-1-8-3) and the absence of upward leading note cluster (No. 6-7-2-9-4) (Page's $L = 2489$, $z = 24.80$, $p < .001$ and Page's $L = 2409$, $z = 11.50$, $p < .001$ respectively). The assumed order of cadences for both groups was from negative to positive values on MDS dimension 2. In line with the findings of Experiment 1, the above also provides some evidence

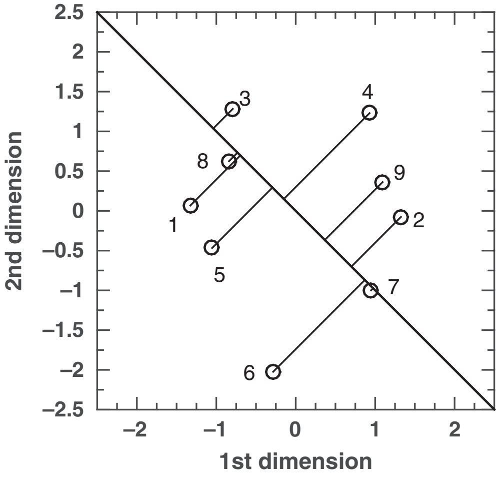

FIGURE 9. The perceptual cadence space with a line of −45° angle. Projection on this hypothetical dimension constitutes a good approximation of perceived tension.

that dimension 2 of Figure 4 is related to perceived tension. However, the trend became even stronger (Page's $L = 12806.5$, $z = 72.33$, $p < .001$) when the ordering of cadences came from their projections on a hypothetical dimensions with a -45° inclination as shown in Figure 9, implying that tension and closure effect (i.e., dimension 1) are not completely independent.

Table 6 shows the Spearman's correlation coefficients between the six rating scales constructed by the mean rating for each of the 18 stimuli (i.e., 9 cadences in both contexts). In agreement with the boxplots presented previously, preference features a very strong inverse correlation with closure effect, expectancy and fit (i.e., stronger closure/expectancy/fit induces less preference than weak closure/expectancy/fit). All these four variables seem to be used in essentially the same manner. An additional Page's trend test for overall preference showed a very strong trend (Page's $L = 13218$, $z = 99.23$, $p < .001$) for increasing preference in line with ordering according to the median values of the boxplot presented in Figure 8 (i.e, 1, 5, 3, 7, 8, 2, 6, 4, 9). Tension is the variable that conveys the highest amount of unique variance within this set being the least related to the others. Nevertheless, it shows medium correlations with closure effect (in line with what was suggested above), expectancy, and fit.

DISCUSSION

Out of all descriptive qualities in the verbal attribute magnitude estimation experiment, *originality* seems to have been least understood (highest disagreement) by the listeners. This finding implies that, despite originality being a commonly agreed measure of creativity, it may not be a clear cut concept within all contexts. In this particular case, it seems possible that many (but not all) listeners might have confused the concept of "originality" (relating to novelty and inventiveness) with the concept of authenticity that relates to genuineness in terms of "origin." In this respect, we speculate that the term "originality" might have introduced uncertainty as to whether it stands for "novelty" or indeed "authenticity."

As a result of the above, we conducted an additional experiment with different participants requesting ratings on two additional scales: *expectancy* and *fit*. These two qualities were highly agreed upon, and expectancy was the only quality that exhibited an effect of harmonic context. It could be argued that the modal context is more "flexible," allowing for more possibilities. The expectancy of cadences that were unexpected in the tonal context (such as the Phrygian and the French sixth) is increased and, at the same time, the expectancy of the perfect cadence is decreased. For all other qualities no effect of harmonic context was revealed. Three factors can be taken into account as a possible explanation of this: 1) the two-bar harmonic progression that defined the tonal/modal context might have been too short to firmly establish the context, 2) the participants were more familiar with the tonal idiom, due to their prolonged exposure to classical Western music, and therefore tended to favor expectancy for tonal cadences even in stimuli with a modal context, 3) the participants tended to conceive chromatic or extended cadential chords as tonal instead of modal since Renaissance modality did not include such sonorities (they were

TABLE 6. *Spearman's Correlation Coefficients Between the Rating Scales*

	Preference	Tension	Closure effect	Expectancy	Fit
Preference	1.0	—	—	—	—
Tension	−.44	1.0	—	—	—
Closure effect	−.86**	.63**	1.0	—	—
Expectancy	−91**	.50*	.94**	1.0	—
Fit	−88**	.56*	.94**	.97**	1.0

Note: **Correlation significant at the .01 level (two-tailed); *correlation significant at the .05 level (two-tailed) historically used only in 19th century modality—e.g., in national musics—as exotic extensions/transformations of chromatic tonality).

The mean ratings on preference, closure effect, expectancy, and fit were highly correlated showing that (in average) participants favored cadences that were less expected, i.e., had a weaker closure effect. This finding should not be generalized, however, as it might well be the case that listeners may tend to prefer more expected/familiar cadences within a more unexpected harmonic background. In other words, unexpectedness might be favored when introducing novelty while expectedness might be favored when resolving high uncertainty. Further experimentation is warranted to validate this hypothesis.

Closure effect that is a direct outcome of the existence of an upward leading note (or lack thereof) seems to be the major contributor as to whether two cadences will be perceived as similar, thus reflecting the categorical perception of cadences that was discussed previously. The fact that closure effect was stronger for cadences featuring an ascending semitone to the tonic (i.e., 1, 3, 5, 8) is consistent with the view held by many theorists that the Phrygian cadence is a weaker intermediary cadence type, hence its appearance in tonal contexts as a cadence on the dominant scale degree (e.g., Aldwell & Schachter, 2003).

Tension is less related to the other qualities and there is indication that it may be associated with the second dimension of the perceptual space. However, tension is not completely independent from closure effect expectancy partly confirming Huron's (2006, Chapter 15, pp. 305-330) view that these qualities are positively related. These results imply that, in general, the higher the expectancy (presence of an upward leading note) the stronger the tension but—according to the results of Experiment 1—within each of the two groups of cadences, tension differentiations can be attributed to the inherent roughness (sensory dissonance) of the penultimate chord and the distance of the pair in the Tonal Pitch Space (tension dissonance). This is in accordance with other—complementary to Huron's—views with regard to musically induced tension in general (Lehne & Koelsch, 2015) and tonal tension in particular (Lerdahl & Krumhansl, 2007).

A more specific look can reveal some characteristics of certain cadences that are also supported by the Page's trend tests presented in the results section. The perfect cadence gets the highest closure effect/expectancy/fit ratings and the Phrygian cadence is rated quite low for closure effect/expectancy/fit while the various products of the cadence blending system fill the space in-between. Moreover, cadences 4 (backdoor progression) and 9 (half diminished fifth) seem to get the highest preference while the perfect cadence receives the lowest preference rating in both harmonic contexts.

Despite the identified categorical perception for the cadences examined in this work, the acquired knowledge of the perceived relationships, in combination with qualitative characteristics, is still valuable for enhancing the creativity of the system. This information can be exploited by the cadence blending system in order to increase its capability for interaction with a human user by enabling refinement of the desired outcome. For example, when the system receives a request to produce a cadence that should be perceived relatively close (i.e., having similar closure effect) to the Phrygian but at the same time featuring higher tension, it will direct itself towards the backdoor progression (No. 4). Another example could be the request to produce a cadence that would feature a similar closure effect compared to the perfect (i.e., close in the perceptual space) but with the highest possible tension. In that case, it should direct itself towards the French sixth (No. 8). Finally, if the request is for a blend that is far away from both the perfect and the Phrygian, the plagal (No. 6) among others is a possible solution. Including such high-level descriptions may potentially enable the integration of additional creative mechanisms that frame conceptual blending theory, e.g., blending elaboration and concept compression, which is currently not possible within the context of the employed structure-oriented modeling.

General Discussion

The purpose of this work was to present a case study of conceptual blending in music harmonic structures and to obtain some insight regarding the way its outcomes are being experienced by human listeners. Using two cadences (the perfect and the Phrygian) as starting points, our system produced several blends, seven of which were selected for empirical assessment. To this end, two listening experiments were conducted to shed some light on cadence perception within and out of harmonic context. Both the relative perception of these cadences and their description on (initially) four selected qualities were obtained.

From the perspective of creativity evaluation, the two input cadences (perfect and Phrygian) were positioned in the maximum distance along the first dimension of the perceptual space. However, no blend occupied a position that was directly in between the original cadences; that is, no blend was double-scope according to the results of the dissimilarity rating experiment. One could maintain that all blends (with a possible exception of the plagal cadence that is considered as an outlier) were perceived as variations of either the perfect or the Phrygian cadence.

For instance, despite the fact that some blends featured salient characteristics from both originals (such as the tritone substitution where both the leading note and the ^♭2 are present and lead to the tonic), cadence perception was categorical, based on the presence or absence of the upward leading note (the tritone substitution can be seen as a single-scope blend that preserves primarily the perfect cadence character but has embodied characteristics from the Phrygian cadence). This resulted in a discrepancy between the system's ranking of blends—whose weighting criteria had not taken the existence of categorical perception into account—and their relative positions on the perceptual space. It can be argued that the presence of the downward leading note ^♭2 in the tritone substitution cadence was overshadowed by the perceptual dominance of the upward leading note and failed to bring cadence No. 3 in the middle between No. 1 and No. 2. This does not seem to confirm our initial hypothesis that the D♭ resolution to the tonic is equally salient to the upward leading note. In our experimental set up, this may also be due to the fact that the upper voice (that always features the upward motion in our case) is of higher perceptual salience compared to the bass (that always features the downward motion) (Palmer & Holleran, 1994; Thompson & Cuddy, 1989).

This finding suggests that blending input spaces with a single mutually exclusive salient property (such as an upward semitone or an upward tone movement towards the tonic) may render the invention of balanced double-scope blends an unfeasible task. Therefore, such a possibility should be considered in system design and selection of input spaces.

In some accordance with the dissimilarity data, the two original cadences were generally rated in the extreme values of expectancy, preference, closure effect, and fit (that seem to be well represented by MDS dimension 1) and have produced seven blends that received various values in between. Additionally, the blends received both higher and lower values of tension ratings compared to the originals. This shows that the blending system is capable of exploring away from its inputs, as Pearce and Wiggins (2001) put it, by exhibiting a variability regarding both perceptual distances and several qualitative attributes, thus highlighting its creative potential.

The hypothesis that the conceptual space represented by the perfect cadence would have higher prominence seems to be confirmed by the data. Its representative cadences induce stronger closure effect and are perceived as more appropriate endings (higher fit) regardless of context. At the same time, this increased predictability is translated into lower preference. Within the group of "tonal" cadences, however, the French sixth (No. 8) and the tritone substitution (No. 3) seem to be more preferred, probably because of the higher amount of surprise they introduce. This is in agreement with the fact that they receive the highest positions in the system ranking (see Table 3) in terms of blend quality and suggests that successful blending of a prominent conceptual space (in our case the perfect cadence) with a weaker one (i.e., the Phrygian cadence) has raised the preference by *introducing an interesting variation*. However, this effect was not conversely evident, given that the Phrygian cadence was already quite appreciated and so were its blended versions.

As a conclusion, this exploratory study on blending of cadential sequences has demonstrated the creative potential of conceptual blending theory when applied to musical harmony. Follow-up research (Kaliakatsos-Papakostas, Queiroz, Tsougras, & Cambouropoulos, 2017) extends the blending mechanism presented here towards blending chord transitions where both chords can vary. This transition blending methodology is used as a basis for blending chord transition matrices that represent the chord transition probabilities of different idioms as learned from data. Thereby, blending between entire harmonic idioms is made possible. Empirical evaluation of the system's success in producing hybrid harmonic idioms is also the subject of ongoing work (Zacharakis, Kaliakatsos-Papakostas, Tsougras, & Cambouropoulos, in press); this requires the application of behavioral approaches capable of assessing longer musical stimuli. The results of the current and follow-up studies suggest that the application of conceptual blending constitutes a promising direction for computational creativity in music.

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