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Emotional processing in music: Study in affective responses to tonal modulation in controlled harmonic progressions and real music

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ABSTRACT

Tonal modulation is one of the main structural and expressive aspects of music in the European musical tradition. Experiment 1 investigated affective responses to modulations to all eleven major and minor keys (relative to the starting tonality) in brief, specially constructed harmonic progressions, by using six bipolar scales related to valence, potency, and synaesthesia. The results indicated the dependence of affective response on degree of modulation in terms of key proximity, and of mode. Experiment 2 examined affective responses to the most common modulations in nineteenth-century piano music: to the subdominant, dominant, and minor sixth in the major mode. The stimuli were a balanced set of both harmonic progressions (as in Experiment 1) and real music excerpts. The results agreed with theoretical models of violations of expectancy and of proximity based on the circle of fifths, and demonstrated the influence of melodic direction and musical style on emotional response to tonal modulation.

INTRODUCTION

The pitch material of virtually all the musics of the world is organized into tonal hierarchies in which the pitch classes of a tonal scale divide the octave into (typically) five to seven steps of a tonal scale, with a stable "home base" in the tonic pitch, and a variety of tonal functions and tendencies assigned to the remaining pitch classes (Dowling & Harwood, 1986). In western music the tonal hierarchy is organized in terms of two principal modes, major and minor, defined in terms of tonal scales of seven pitch classes (Krumhansl, 1990). The seven pitch classes of a mode are selected from the set of twelve logarithmically equal steps (semitones) into which the octave has been divided by the system of equal-tempered tuning adopted in Europe beginning in the early eighteenth century (Robinson & Needham, 1962). All the intervals defined by a mode are defined in terms of numbers of semitones, so any of the twelve possible pitch classes can be chosen as the tonic pitch of a musical "key" (for example, C major, or E minor). Hence a melody played in one key can be shifted to another key without distorting its melodic intervals. This system makes possible a shift of keys within a piece, which is called "modulation."

Tonal modulation involves a shift of tonal center within the same musical composition, involving a transition to a different key (tonality) with a new scale of pitch classes. Modulation is one of the main structural and expressive aspects of music in the European musical tradition. Relationships among tonalities are described in terms of the circle of fifths (Diletsky, 1677; see Fig. 1). The circle of fifths arises because you can start with any pitch class and go up or down by 7 semitones (a musical "fifth") and arrive at a tonal center whose major scale differs from the original scale by just one altered pitch. In Figure 1 this is illustrated by going from C up a fifth to G. The key of G major has one altered pitch (F#) with respect to the key of C major. The second example in Figure 1 shows what happens if we go up clockwise by five fifths around the circle, landing on B and adding five sharps (#) to alter the pitches of the scale. The more steps (in the shortest direction) between two pitches on the circle of fifths, the more differences between the two pitch sets that define the tonalities represented by these letters, Modulations can thus vary in the distance over which they travel in tonal space from one key to another. The greater the distance, the more complicated and surprising they are likely to be.

Insert Fig. 1 about here

Modulations can also vary in the relationships between the original and target modes. Each of the twelve available steps around the circle of fifths can be the center for two tonalities, one in a major mode and another in a minor mode, so that there are four possible modal relationships involved in modulations: Major-Major, Major-minor, minor-Major, and minor-minor. The major mode is generally characterized as happy, and the minor mode as sad. The affective influence of the major and minor modes has been thoroughly investigated (Hevner, 1935; Kastner & Crowder, 1990; Panksepp & Bekkedal, 1997; Gagnon & Peretz, 2003; Webster & Weir, 2005; Halpern, Martin, & Reed, 2008).

Previous studies have demonstrated that listeners are able to track modulations in that their cognitive responses in terms of tonal-hierarchy profiles and ratings of tonal distance or tension are differentially affected (Firmino, Bueno & Bigand, 2009;

Krumhansl & Kessler, 1982; Lerdahl & Krumhansl, 2007; Thompson & Cuddy, 1989, 1992; Toiviainen & Krumhansl, 2003). The process of following the reorientation of a tonal center is guided by musical expectations and by perceived tonal tension (Meyer, 1956; Lerdahl & Krumhansl, 2007). In modulation, the degree of the perceived change in tonal tension increases with key distance (Bigand & Parncutt, 1999; Firmino et al., 2009) and is greater with clockwise (vs. counterclockwise) motion in the circle of fifths (Toiviainen & Krumhansl, 2003). We also think it plausible that tension should be greater for the minor (versus the major) mode due to its greater complexity, though we have not found direct behavioral tests of that possibility.

While there is a general agreement that music elicits emotions (Huron, 2006; Juslin & Sloboda, 2010), the mechanism of communication of affective states by music is still unclear, mostly because of the non-representative nature of music. In music we are dealing with aesthetic emotion that is a purely human experience involving the presence of beauty (Florensky, 1925), non-pragmatic interest (Scherer & Zentner, 2008), cultural construct (Stevens, 2012), and personal subjective experience (Vuoskoski & Eerola, 2011). It is well known from musical practice that modulations of different tonal distances have characteristic effects on the listener. It is also known that some modulations, such as that of an ascending lowered sixth in a major mode, are popular in sudden tonal reorientation, and that modulations to the dominant and subdominant are routine for the classical forms such as Baroque fugue and sonata allegro form (Rosen, 1988).

Modulation is viewed in western music theory as a principal tool of thematic harmonic development (Caplin, 2000), and through its effects on expectations appears likely to affect the listener's emotional responses. To our knowledge, there has been no systematic exploration of emotional responses to modulations to a wide range of target keys in tonal space. In Experiment 1 we compare a baseline non-modulating chord progression (in either the major or the minor mode) to progressions that modulate to all the major and minor keys. We include shifts within the same key from major to minor (C major-C minor, C minor-C major). Hence Experiment 1 explores an array of 48 types of trial: 4 modal relationships (Major-Major, Major-minor, minor-Major, minor-minor) X 12 target keys (including the baseline non-modulations).

We hypothesized that affective responses to these progressions would depend on tonal proximity, modal relationships, as well as the influence of melodic direction (controlled in Experiment 2). These properties of the music all affect the listener's expectations, which in turn generated affective responses (Meyer, 1956). For example, the chord progression, common in Baroque music, that starts with a move of the root of the chord three steps clockwise on the circle of fifths (C - A) and then returns to the tonic via a descending sequence of fifths (counterclockwise: A - D - G - C) involves a tension-inducing violation of expectancies in the initial leap, followed by progressively more predictable and calming resolutions as we approach the tonic. (For an example, see Bach's *Das Wohltemperierte Klavier,* Book I, Prelude in C Major, measures 4-8, but with the additional complications that the ii-chord on D is transformed into the dominant seventh of the G chord, and the final resolution to the C chord leaves us hanging because it is to a seventh chord with the seventh in the bass. This example also involves the effects of melodic motion, since the initial move involves a step up, from G to A, and from then on the most obvious motion down: C and A to B and G, D to C.) And the minor mode, being more complex than the major, is more unpredictable.

In order to assess the effects of expectancy on responses to the modulations we divided the 48 types of modulation (12 steps X 4 major-minor mode conditions) into cases where the final chord was relatively expected in the context of the original tonality, cases where it was unexpected, and cases where expectations were ambiguous. Our

Insert Table 1 about here

categorizations are shown in Table 1. The *Expected* final triad is built on one of the diatonic steps of the opening tonality (except the diatonic seventh step, since neither a major nor a minor triad can be built on this step using the diatonic tones). We also included nonmodulating Major-minor and minor-Major transitions in this category, taking into consideration the power of retaining the same tonic. The *Unexpected* closing triad has at least one tone that is foreign to the diatonic steps of the opening tonality, and does not meet any of the conditions of the ambiguous category, below. The *Ambiguous* final triad contains pitches foreign to the original tonality, and either (i) the tonic of the opening tonality as a third in the final triad, or (ii) the third diatonic step of the opening tonality as a root of a final triad, or (iii) approaching semitones to a tonic triad of the opening tonality (see Figure 4 for illustration). There are two exceptions for the Ambiguous group: the minor triad on the dominant (up 7 semitones) and the triad on the supertonic (up 2 semitones) in the minor-minor condition. According to the rules of classical tonal harmony a triad on the dominant is expected to be in a major mode. The exception for a triad on a supertonic in the minor-minor condition is dictated by the alteration of the sixth diatonic step in the melodic minor.

We hypothesized that expected resolutions would be judged to have more positive valence and greater strength than unexpected thanks to the shared pitches among the opening triad and expected triad, and that ambiguous resolutions would fall somewhere in between those two.

We measured listeners' affective responses with a set of 6-point bipolar adjective scales related to mood valence (happy/sad; pleasant/unpleasant), potency (strong/weak; firm/wavering), and sensory experience (bright/dark; warm/cold). We used the first four adjective pairs because of their long history in studies of affective response going back to the work of Osgood, Suci, and Tannenbaum (1957). We considered using adjectives from Osgood et al's activity factor as well, but pilot work convinced us that listeners were confusing physical activity in the music with its portrayal of affect. Hence we used two adjective pairs instead that invoke sensory metaphors that are often used by musicians and music listeners.

Following Experiment 1, which utilized specially constructed brief chord progressions, we wanted to generalize our findings to modulations as they actually appear in real musical contexts. Therefore for Experiment 2 we set out to find a matching set of actual musical passages that involved the modulations we had been studying. In this we were limited by musical practice in the eighteenth and nineteenth centuries, in which only a few of the possible modulations were used with any appreciable frequency. We counted modulations occurring in a broad sample of 132 piano pieces from this period (see Fig. 2), and found that there was no possibility of exploring mode systematically (because no

Insert Fig. 2 about here.

modulation was used sufficiently often in all four mode combinations). Therefore in Experiment 2 we focused on the three most frequently used modulations in the Major-Major condition: modulations to the subdominant (step 5), the dominant (step 7), and the ascending minor sixth (step 8) and selected eight instances of each modulation (see Appendix I). We matched each of these natural modulation types with a set of specially constructed progressions (as in Experiment 1), in which we also controlled melodic direction in the soprano and bass melodic lines. It also strikes us as plausible that upward melodic motion would increase tension, whereas downward motion should decrease tension. The often observed tendency of melodies to rise at the beginning and fall at the end suggests that that may be the case. Experiment 2 used the set of adjective scales from Experiment 1 with the exception of the pleasant/unpleasant scale being replaced with the relaxed/tense scale. Listeners in Experiment 1 tended to rate all the stimuli as at least moderately pleasant, which reduced that scale's ability to discriminate among the stimuli. Also, what information was provided by that scale tended to duplicate the results from the happy/sad scale. And our thinking about the issues involved in these experiments led us to realize that a relaxed/tense scale would be very useful. By using the balanced set of controlled harmonic progressions and real music excerpts in Experiment 2, we were able to compare the affective influence of degree of modulation when modulation occurs with and without the context of other expressive aspects of music, such as tempo, register, and dynamics. In addition, the diverse set of real music stimuli selected from the music of the

First Viennese School and the Romantics permitted us to explore the influence of musical style on the affective response.

Experiment 1

METHOD

Participants

Sixty-nine psychology students from the University of Texas at Dallas, 54 females and 15 males (aged 19–53, with a mean age of 24.8 years, SD = 7.2) participated in Experiment 1 to fulfill a course requirement. We divided them into four levels of musical training, depending on years spent taking music lessons on an instrument or voice, and playing in an instrumental ensemble. Fourteen participants had less than 1 year of musical training, 18 had 1 to 3 years, 18 had 4 to 6 years, and 19 had more than 6 years. We divided them into four groups because we wanted groups of approximately equal size, and previous research has shown that the most important thresholds for the effects of experience on behavior are somewhere around 1 or 2 years and around 6 years (for example, for memory encoding of melodies, Dowling, 1986).

Stimuli

The first author wrote 12 chorale-like harmonic progressions consisting of eight chords, one for each of the 12 steps of the chromatic scale. A choice of the beginning tonality in each modulation was random. The variants of the minor mode (natural, melodic, and harmonic) were determined by the dictates of smooth voice leading. This was done so that listeners would not get used to hearing every trial begin in the same key, but rather be encouraged to hear each trial in its own terms. Since the majority of the listeners do not have perfect pitch (Dooley & Deutsch, 2011), the absolute pitch level of the opening and concluding keys are generally irrelevant. Our main interest was the affective influence of the *degree* of modulation. The stimulus set included the zero-step or non-modulating condition to provide baseline data against which to compare responses to modulations in which the tonal center shifted in pitch. It also allowed us to assess the effect of shifts between major and minor modes with the same tonic, a fairly common practice in western music since 1600 (as in the use of "Picardy third"). Table 2 shows the degree of modulation in semitones, the position of the pivot chord in the modulation, and the number of different types of chord in the modulation. (The pivot chord is common to both the initial and the target tonality.) These 12 progressions were then modified to

Insert Table 2 about here.

obtain four versions of modulation to each scale degree: from Major to Major mode (M-M), from Major to minor (M-m), from minor to Major (m-M), and from minor to minor (m-m). The first three to five chords in each progression established the opening tonality and the following transitional chords made a smooth modulation to a target tonality via an authentic cadence (that is, a progression from the dominant chord to the tonic chord in which the tonic pitch occurs in both the bass and the melody line). Some modulations demanded fewer transitional chords than others (see Table 2). There were no sudden unexpected juxtapositions of chords in the progressions, and the progression employed smooth voice leading. The 48 progressions differed in the tonal distance of the modulation, in rhythm (slightly, where passing tones were required for a smooth progression), in the voice leading, and in the number of functionally different chords. The progressions were alike in tempo, were isochronous (apart from the passing tones), style, sound intensity, timbre, and range. The stylistic unity of the progressions prevented the interaction of mode and texture (Kastner & Crowder, 1990; Webster & Weir, 2005). Each progression was comprised of 8 chords. The progressions were 11 sec in duration (MM = 72 beats/min¸ with each chord on a beat) and included a slight *ritenuto* at the end to make the modulation sound natural. The last chord was 3 sec in duration to emphasize the closing tonality. Each progression was followed by a delay of 10 sec. There were two different random orders of stimuli for Experiment 1, each given to approximately equal numbers of participants at each training level. The stimuli were digitally recorded as CD-quality .wav files by the first author playing a Yamaha grand piano, and were presented to participants via loudspeakers with high-quality stereophonic equipment.

Procedure

The participants were asked to indicate the intensity of their affective responses to the concluding part of each progression on six bipolar adjective scales (Osgood et al., 1957): the valence scales happy/sad and pleasant/unpleasant, the potency scales strong/weak and firm/wavering, and the sensory scales warm/cold and bright/dark (Eitan & Timmers, 2010). This choice of adjective scales did not adhere strictly to the three main categories of valence, activity, and potency obtained by Osgood et al., since pilot work in our laboratory had found that listeners have difficulty using activity scales consistently with modulating sequences. The choice of the sensory scales was based on the popularity of the adjectives bright/dark and warm/cold among musicians and listeners describing music that changes primarily in harmonic modulation. We cannot exclude the influence of music variables other than the relationships between harmonies in modulation; for example, melodic motion upward and downward could be a confounding factor in the perception of modulation (we addressed the possible influence of this specific variable in Experiment 2, below).

The participants were asked to place a mark on a six-point scale labeled with the bipolar adjectives at each end to indicate their feeling about the concluding part of each progression, in effect their judgment about what emotion they perceived in the target tonality. For each stimulus participants had a sheet of paper showing six tables. Each table pertaining to a progression and showing the six bipolar adjective scales presented in various random orders. On each of eight answer pages, the order of adjective scales in the table was scrambled for each stimulus. In the course of a training session the participants heard and rated four sample stimuli representing different modal conditions. The results of the training session were discussed with the participants to ensure that they understood the task. The participants were tested in group sessions, with two to nine persons per group. Each of the 48 progressions was presented once.

RESULTS

In order to get an overall picture of the patterns of relationships in the data, we first subjected them to principal components analysis (PCA). We found that the grouping of adjective pairs by our listeners, as shown in the PCA, is different from our a priori grouping: they treated happy/sad and bright/dark as essentially synonymous, and pleasant/unpleasant and warm/cold as very similar in meaning, while agreeing with us in the grouping of strong/weak and firm/wavering. Therefore, we used these three groups of adjective scales in subsequent analyses, by subjecting the data to three analyses of variance (ANOVAs), one for each group of adjective scales taken as the dependent variable. Each ANOVA was carried out on 4 levels of musical training X 12 scale steps of modulation X 4 modal relationships, in which only musical training involved a between-groups comparison. Following that, we reduced the 48 (12 steps X 4 modal conditions) modulations to the three expectancy categories shown in Table 1, and subjected those results to a 4 levels of musical training X 3 expectancy categories X 3 groups of adjective scales ANOVA, in which musical training involves a between-groups comparison, again using the groups of adjectives indicated by the PCA. We report strength of effect in the ANOVA results as *Total* R^2 (the sum of squares for the effect divided by the total sum of square), and we use the Greenhouse-Geisser correction in evaluating statistical significance for corrections of violations of the sphericity.

Principal component analysis for harmonic progressions

The first two dimensions of the PCA on the ratings of the 48 harmonic progressions are shown in Figure 3 and explain more than 95 % of the variance. The first component (τ = 85.2 %) is defined by the valence-related scales (happy/sad and bright/dark), whereas the second component (τ = 10.9 %) is defined by the potency-related scales (strong/weak and firm/wavering). The two remaining scales (pleasant/unpleasant and warm/cold) are related to each other somewhat closely and fall midway between the two principal components.

Insert Fig. 3 about here

The Target tonalities in the major mode (diamonds and squares) are clustered on the side of positive connotations (happy, bright, pleasant and warm), whereas target tonalities in the minor mode (dots and triangles) fall mostly on the negative side (sad, dark, unpleasant and cold). On the negative side, the prominent “sadness” and “darkness” of the dominant step (fifth scale degree, up 7 semitones) in the Major-minor and minor-minor conditions probably indicates the “oddness” of such a modulation. (According to the rules of classical functional harmony, a target tonality on the dominant should ideally be in a major mode—Schoenberg, 1954). The presence of such ecologically unlikely stimuli in our study was the consequence of the experimental design that used all degrees of modulation and all possible modal conditions. Among other well-differentiated target tonalities on the negative side are the target tonalities based on a lowered leading tone (step 10) of the original key in the minor-minor condition, and on a tritone (step 6—a non-scale pitch of the original key) in the minor-minor condition. These two steps are also an exception for the modulations ending in a major key, as only the major target tonalities on steps 10 and 6 in the minor-Major condition fall on the negative side of the first component.

On the positive side of the first component, the modulations with the most positive valence are target tonalities in the major going up 1 semitone, 8 semitones, and 5 semitones (the subdominant). In musical practice, the major target tonalities on step 1 (a lowered second) and step 8 (a minor sixth) are the popular targets of a deceptive cadence. These major tonalities have special relationships with the subdominant triad that consists of scale degrees 4, 6, and 1. The major tonic triad that is the target of a 1-semitone modulation is comprised of the scale degree 4, a lowered scale degree 6, and a lowered scale degree 1; for the opening tonality, a first inversion of this triad can be explained as a subdominant triad in a minor mode and with an approaching semitone towards scale degree 1, whereas the major tonic triad that is the target of an 8-semitone modulation represents a relative major tonality for this subdominant chord in a minor mode. For instance, in the C major tonality, a first inversion of the target triad of a 1-semitone modulation (f—a-flat—d-flat) can be explained as an F-minor chord with an approaching semitone (d-flat) towards scale degree 1, whereas an A-flat major triad, which is the target of 8-semitone modulation, represents a relative major tonality for the F-minor. These relationships impart a subdominant feel to these 1-semitone and 8-semitones target tonalities, and we see that participants tended to group these target tonalities with the subdominant (5). (For a real-music example, see Schumann's *Novelletten* op. 21 No 1, measures 35-37, where a deceptive cadence on G-flat major triad (instead of F major) is followed by an inversion of a dominant seventh chord on C, which resolves on F major; here the G-flat triad (on a lowered scale degree 1) serves as a "representative" of the subdominant sphere in F major).

Two important cues that may be related to the positive feeling about the modulations to steps 1, 8, and 11 in a major mode are the importance of approaching semitones, and interchangeability of a tonic and a mode-defining tone (see Figure 4).

Insert Fig. 4 about here

On the PCA plot, the second component (τ = 10.9%) is defined by the potency-related scales strong/weak and firm/wavering. The modulations to the dominant (up 7 semitones) were sensed as the "strongest" and "firmest" among all steps, as if validating the "dominant" name. And the weakest modulations are those that go up 4 semitones, followed by those going up 2 semitones.

As can be seen in Figure 3, the adjective pairs pleasant/unpleasant and warm/cold were loosely grouped in between the first two components, and share certain properties with them, but do not represent an independent dimension.

Analyses of variance

We carried out three ANOVAs, each of which took the pooled responses to one of the groups of adjective scales derived from the PCA: valence (happy/sad, bright/dark), potency (strong/weak, firm/wavering), and what we will call "pleasantness" (pleasant/unpleasant, warm/cold). The design of these ANOVAs was 4 levels of musical training X 12 scale steps of modulation X 4 modal relationships, in which only musical raining involved a between-groups comparison.

Valence. The ANOVA on the valence scales (happy/sad, bright/dark) showed that with increased musical training responses became less positive, F (3,65) = 5.33, R^2= 1.25%, $p < .01$, with mean valence ratings (on a 6-point scale) going from 3.65 for training level 1 to 3.36 for level 4. There was a significant effect of step of modulation, F (11, 715) = 5.44, R^2 = 2.3%, $p < .001$, reflecting the effects seen in the PCA. And there was a relatively strong effect of mode condition, F (3, 195) = 55.01, R^2 = 5.1%, $p < .001$, with major keys receiving a higher valence rating than minor keys, with the rating determined more or less equally by the initial and the target key (see Fig. 5). No other effects were significant.

Insert Fig. 5 about here

Potency. The effect of mode on potency ratings (strong/weak, firm/wavering) was similar to that for valence, but was apparently only influenced by the final mode, F (3,195) = 4.18, R^2= 0.3%, $p < .05$, with ratings of 3.62 (Major-Major), 3.54 (Major-minor), 3.69 (minor-Major), and 3.57 (minor-minor). Nevertheless, the effect of mode on potency was basically in the same direction as the effect on valence, with major rated stronger and firmer than minor. The musical training X mode condition interaction was significant, F (9,195) = 2.93, R^2= 0.6%, $p < .01$, with no individual training level group showing the main effect just noted, but each of them departing from it slightly in different directions. And the interaction of scale step of modulation and mode condition was significant, F (33,2145) = 2.53, R^2= 1.9%, $p < .001$, and is shown in Table 3. The general pattern of the main effect of mode on potency was shown by some of the steps of modulation, notably steps 1, 5 and 8, noted above for having the most positive valence. But that pattern was hardly apparent at all for steps 4, 6, 9, 10 and 11. Step 7, the dominant, showed a contrary pattern, with strong ratings overall, especially for modulations starting in the minor, reflecting the pattern in the PCA (Fig. 3). Note that the strength of these effects is quite weak, reflecting the fact that most of the variability is accounted for by the effects of mode, particularly on valence but also similarly on the other scales, as seen in Figure 3. No other effects were significant.

Pleasantness. Pleasantness ratings (pleasant/unpleasant, warm/cold) showed the same effect of mode as shown in Figure 5, but somewhat less strongly, with the range of ratings spanning 0.74 points (vs. 1.13 points for valence), F (3,195) = 39.62, R^2= 3.5%, $p < .001$. Pleasantness ratings also decreased with increased musical training, from 4.08

for level 1 to 3.62 for level 3, with level 4 somewhat higher at 3.72, F (3,65) = 8.81, R^2 = 2.7%, $p < .001$. And the modulation step X mode condition interaction was significant, F (33,2145) = 2.19, R^2= 1.6%, $p < .01$. The responses to all of the modulations except those to steps 2 and 9 closely resembled the pattern in Figure 5. Steps 2 and 9 showed a steady decline from left to right across the figure, but with less of a decline from Major-minor to minor-Major than elsewhere. That pattern suggests that what is important is simply the amount of major versus minor in the whole stimulus. No other effects were significant.

Analysis of variance for Expected, Unexpected, and Ambiguous categories

As described in the introduction, we predicted the degree to which the tonic chord of the target step of modulation would be expected on the basis of the original tonic (see Table 1). We categorized the 48 stimuli into expected, unexpected, and ambiguous modulations. This provided a considerable simplification of the patterns of the 12 steps of modulation and the 4 modes.

We subjected the data to a 4 training levels X 4 modal conditions X 3 expectancy categories X 3 adjective scale groups (from the PCA), with training level as the only between-groups variable. There was a main effect of modal condition, showing the same pattern as in Figure 5, F (3,195) = 81.89, R^2 = 14.1%, $p < .001$. There was a main effect of expectancy category, F (2,130) = 26.48, R^2 = 2.0%, $p < .001$. As hypothesized, the ratings were more positive across all three adjective scales for the expected (3.64) than the unexpected (3.49) modulations, with the ambiguous modulations in between (3.59). There was a significant interaction of mode condition X expectancy category, F (6,390) = 6.17, R^2 = 1.1%, $p < .001$, in which only the mm condition showed the hypothesized pattern of expected (3.33) higher than unexpected (3.16) with ambiguous in between

(3.27). When the modulation ended in the major the ambiguous category was rated at least as high as the expected (see Table 4). There was also a significant interaction of training level X mode condition X expectancy category, F (18,390) = 1.97, R^2 = 1.0%, $p < .05$, in which there was little in the way of a discernible pattern that could support a generalization.

Of more interest was the effect of adjective scales, F (2,130) = 25.43, R^2 = 3.2%, $p < .001$, which indicates that the ratings on the three groups of adjective scales, discussed separately above in the discussion of the ANOVAs carried out across all twelve steps of modulation, are in fact different from one another. These differences are quite apparent in the interaction of modal condition X adjective scale group, F (6,390) = 47.19, R^2 = 6.3%, $p < .001$, and can be seen in the column means in Table 5. The valence and

Insert Table 5 about here

"pleasantness" scales show the pattern across modal conditions seen in Figure 5, more strongly for valence than pleasantness, and the potency scales showing the effect of ending in the minor, discussed above.

The principle evidence for the effects of expectancy can be found in the interactions of expectancy category X adjective scale group, F (4,260) = 8.49, R^2 = 0.6%, $p < .001$, and of modal condition X expectancy category X adjective scale group F (12,780) = 7.53, R^2 = 1.1%, $p < .001$. The former can be seen in Table 5. Ambiguous modulations were rated highest and unexpected modulations the lowest on the valence scales, whereas expected modulations were rated slightly higher than ambiguous on the potency scales, again with unexpected modulations lowest. And as could be expected from the PCA, responses to the pleasantness scales fell between those patterns. Table 5 shows the latter interaction, which adds modal conditions to the picture. Here we see that for the valence scales the pattern of Figure 5 holds only for the expected and ambiguous modulations, and for the pleasantness scales, only for the expected. For the potency scales, none of the expectancy conditions shows the effect noted above of lower potency ratings for modulations ending in the minor; rather for stimuli that stayed in the major, expected and ambiguous modulations received higher ratings. Ratings were constant across expectancy categories for major/minor modulations, and for modulations beginning in the minor, expected modulations were rated higher than the other two categories. Some details of this pattern were discussed above with regard to the ANOVA on the potency scales across the twelve steps of modulation.

Overall, the tonalities in the Expected group were perceived as strongest and most positive. This speaks for a perceived certainty of the Expected triadic endings, all of which were based on diatonic steps of the opening tonalities. In contrast, the Unexpected modulations appeared as less positive and weaker. In comparison with the Expected and Unexpected groups, the Ambiguous group in some instances in Table 5 demonstrated a stronger contrast in response to the major and minor endings. The character of responses to the Ambiguous and Unexpected modulations illustrate the difference between a pleasant tonal surprise and a not-so-pleasant surprise.

DISCUSSION

The participants sensed different affective content in the different degrees of modulation. They recognized the importance of the subdominant (5) and dominant (7), which both are close in key proximity, and the “pleasantness” of modulations in a major mode to the lowered second (up 1 semitone), the leading tone (up 11 semitones), and the minor sixth (up 8 semitones). The participants indicated negative feelings about modulations to the tritone (6 semitones) and the flattened leading tone (up 10 semitones). The most interesting results of Experiment 1 are related to perception of distant modulations. The results suggest the importance of approaching semitones and mode-defining thirds for the perception of functional harmony, at least when modulation is in a major mode. For example, the distant modulations in a major mode to step 1 and step 11 each introduce five new pitches, whereas modulation to step 8 introduces four new pitches. These “pleasant-surprise” modulations represent tonalities that are situated far away from each other on the circle of fifths. It appears that the effect of tonal distance is alleviated by the mutual “leading” qualities of the opening and concluding tonic triads in modulation to step 1 and step 11 and the “pseudo-stability” for modulation to step 8. Perhaps these “leading” and “pseudo-stability” properties of the tonal relationships between an opening triad and a concluding triad in modulating passages enhance a comforting sense of resolution for the leading kind of modulation, and stability (for the pseudo-stability kind), despite the considerable difference in pitch set between the two tonalities. In contrast, the listeners did not find the modulation to the flattened leading tone (10) in the Major-Major condition very pleasant, though that modulation introduces only two new pitches. There are clearly factors other than key distance that influence our affective perception of modulation.

This sensitivity to the flattened leading tone was captured in Krumhansl and Kessler’s (1982) study where the profiles of two relative tonalities, C major and A minor, were superimposed. In this superimposition, the pitches A and G showed the greatest difference in ratings. A is the tonic in A minor, and whereas G occurs in the A minor scale in the natural and descending melodic versions, an unaltered G sounds as a “flattened” leading tone for the harmonic and ascending melodic versions. The diatonic seventh tone G in the A minor scale does not have the important status of a “tense” leading tone, which makes it “unsuited” to function as a critical component of the dominant triad, according to the rules of conventional harmony.

The importance of leading and approaching semitones in the relationship between tonic triads was taken into consideration during the categorization of the target tonalities as Expected, Unexpected, and Ambiguous in the present study (see Table 1). According to the principle of the “shortest path” (Lerdahl, 2001), major keys on the ascending semitone (1), descending semitone (11), and ascending minor sixth (8) are situated far away from a tonal center on the key-proximity map. Yet it seems that the special condition—the presence of the leading and approaching semitones and the transformation of a root into a mode-defining third--made these relatively distant modulations easier to follow. Historically, the crystallization of the triadic relationships of functional harmony from the organically interwoven voices of polyphony transformed the meeting points of melodic voices into independent entities—chords. The Baroque tradition of melodic voice leading and the very phylogeny of the tonal hierarchy (defined by perceived tonal tension for which the leading tone plays an important role) determined the perception of tonal harmony and the formation of preferences in modulation.

Since the number of minor and major chords in the progressions was not controlled (because different degrees of modulation demanded different number of transitional chords), it is possible that the difference in the number of minor and major chords could be a confounding factor in perception of modulation. Overall, the results of the Experiment 1 demonstrated that listeners perceived differences in mode and degree of modulation and recognized the targets of popular modulations even when presented with minimal musical context.

Experiment 2

Experiment 2 examined emotional responses to 24 modulating excerpts from the classical and romantic piano literature, and also to 24 controlled harmonic progressions matched in degree of modulation. Only three modulations in the Major-Major condition were studied: the near-key modulations to the dominant (up 7 semitones clockwise the circle of fifths) and the subdominant (up 5 semitones)—each one step around the circle of fifths—and the distant modulation going up 8 semitones (four steps counterclockwise around the circle of fifths). This selection of target tonalities was determined by the availability of these modulations in the piano literature of the 18th and 19th centuries. Figure 2 shows the results of a survey we made of that literature, in which 59 % of the modulations that remain in the major were to these three target keys. Corresponding to the eight modulations of each target type drawn from actual piano music, we constructed eight modulations like those used in Experiment 1 to provide a comparison between responses to the modulation embedded in a stylistically rich context and responses to the modulations isolated from other contextual features in the music. Because we had more stimuli for each type of modulation than we did in Experiment 1, we were able to control the patterns of ascending and descending lines in the bass and treble parts, that had been shown to have an effect on affective response (Hevner, 1936; Sloboda, 1991; Toiviainen

& Krumhansl, 2003). Of the eight stimuli of each target type, four had ascending and four descending melodic lines, and similarly for the bass lines. These patterns were systematically counterbalanced so that there were two stimuli that had each of the pairings of ascending and descending treble and bass lines.

The comparison of the highly controlled and artistically impoverished harmonic progressions with the real music excerpts that differed in tempo, rhythm, tessitura, duration, and style, provided the possibility of assessing the influence of the degree of modulation in isolation, as well as the contributions provided by the richer musical context.

METHOD

Participants

Sixty-five participants (49 females and 16 males, ages 19–47 years, with a mean age of 25.2 years, SD = 6.6), all of whom were psychology students at the University of Texas at Dallas, took part in the experiment to fulfill a course requirement. Thirty-one participants (25 females, 6 males) with more than 3 years of musical training (lessons on an instrument or the voice, or playing in an instrumental ensemble--mean duration = 6.1 yr, SD = 2.9) were classified as moderately trained. Because, unlike in Experiment 1, the median amount of training was about where there is a qualitative shift in memory performance (as in Dowling, 1986), we analyzed the data in terms of two levels of experience.

Stimuli and apparatus

The principal experimenter wrote 24 short, largely isochronous, chorale-like harmonic progressions as in Experiment 1: eight modulations each to the target tonalities modulating up 5 semitones (subdominant), up 7 semitones (dominant), or up 8 semitones (an ascending minor sixth). For each of these three target tonalities, four progressions had a rising soprano line and four progressions had a falling soprano line. Each of these sets of four progressions had two progressions with a falling bass line and two progressions with a rising bass line, giving two progressions for each combination of rising and falling soprano and bass lines. (The melodic contour conditions were labeled as the following: RR = rising soprano and rising bass lines, FF = falling soprano and falling bass lines, RF = rising soprano line and falling bass line, FR= falling soprano line and rising bass line). This balanced set was intended to assess the expressive influence of voice leading (Hevner, 1936; Sloboda, 1991; Toiviainen & Krumhansl, 2003). In each harmonic progression, the first three to five chords established an opening tonality and the following chords made a smooth modulation to the target tonality, concluding with an authentic cadence. The progressions were played at a moderate tempo (MM = 72 beats/min¸ with each chord on a beat), with a slight *ritenuto* at the conclusion to make the brief modulations sound more natural. Apart from the control of rising and falling soprano and bass lines, these stimuli were essentially like those of Experiment 1: each progression was comprised of 8 chords and was approximately 11 sec in duration.

The first author also collected and recorded 24 excerpts from classical piano compositions, which represented the same modulations. The length of the excerpts was determined by the following selection criteria: 1) short duration, 2) the presence of several different chords, and 3) the relative completeness of the musical thought. The excerpts were between 16 and 30 sec in duration. To ensure that the initial tonality was well established, each trial began with a tonic triad in the opening key of the excerpt.

All 48 stimuli were in the Major-Major mode condition. They were recorded as CD-quality .wav files by the experimenter playing a Yamaha grand piano with stylistically appropriate phrasing, tempo, and dynamics. Two different random orders of the stimuli were presented to approximately equal numbers of participants with high-quality stereophonic equipment via loudspeakers.

Procedure

The experimental procedure in Experiment 2 was the same as in Experiment 1: participants were asked to indicate their affective response to each stimulus on six bipolar adjective scales. There was a difference from Experiment 1: the pleasant/unpleasant scale was replaced with the relaxed/tense scale. This replacement was introduced because the pleasant/unpleasant scale had not grouped really closely with the valence scales with which we had expected it be grouped, and using the relaxed/tense scale provided for direct comparisons to earlier studies that measured perceived tension (Bigand, Parncutt, & Lerdahl, 1996; Toiviainen & Krumhansl, 2003; Nielsen, 1983). Because in Experiment 1 the pattern of responses to the pleasant/unpleasant scale resembled those to the warm/cold scale, we expected that this replacement would not result in much loss of valuable information.

RESULTS

As in Experiment 2 we started with a PCA to provide an overview of the relationships among the response patterns, followed by a more particular testing of the results via ANOVAs. We will start will the analyses of the isochronous harmonic progressions, followed by the analyses of the musical excerpts.

PCA for Harmonic Progressions (HP)

Together the first two components accounted for more than 99% of the variance. The greatest portion of variability ($\tau = 73.1\%$) reflected a valence dimension characterized by bright/dark and warm/cold, with happy/sad going in more or less the same direction. The second component ($\tau = 26.9\%$) was defined by potency scales firm/wavering and strong/weak (Figure 6). Modulations to steps 7 (dominant) and 8 fell on opposite ends of the first component: target tonalities on step 8 "dark" and "cold," whereas target tonalities on the dominant were recognized as the "warmest" and "brightest." Modulations to the subdominant (5) were sensed as "weak" and "wavering."

Insert Fig. 6 about here

The relaxed/tense scale fell between these two components with "relaxed" being a combination of "warm" and "weak," and "tense" a combination of "dark" and "strong." When we applied PCA to find the degree and pattern of variability for the four melodic contour condition in soprano and bass lines, the results showed a somewhat different alignment of adjective scales than the PCA for the steps: the happy/sad scale was now more closely aligned with the valence group ($\tau = 71.9\%$), whereas the tense/relaxed scale was more closely aligned with the potency group ($\tau = 19.0\%$). Affective responses to modulations in the harmonic progressions were influenced by the direction of melodic contour in the soprano and bass lines (see Figure 7). The progressions with rising soprano and bass lines (triangles) fell mostly toward the "bright," "warm," and "happy" end of the first component, whereas progressions with falling soprano and bass lines (squares) fell mostly toward the "sad," "dark," and "cold" end. For the mixed-direction contour patterns, expanding-tessitura progressions fell on the “bright,” “warm,” and “happy” side (HP 8, HP 9, and HP 15), whereas contracting-tessitura progressions fell on the "sad,” “dark,” and “cold” side (HP7, HP23, & HP24).

Insert Fig. 7 about here

Analysis of variance for Harmonic Progressions (HP)

We carried out six ANOVAs, one for each adjective pair taken as a dependent variable, with the design 2 training levels X 3 steps of modulation X 4 melodic contour patterns, where training was the only between-groups comparison. We did this, instead of the analysis in Experiment 1 that included three scale clusters as a factor, because the six scales did not cluster as neatly in the PCA, and we wanted to focus on the performance on each particular scale in relation to the PCA. We considered a 6 X 2 X 3 X 4 ANOVA to be rather unwieldy.

For the happy/sad adjective scale the effect of modulation step was significant, F (2, 126) = 19.71, R^2 = 3.7%, $p < .001$, with modulation to the dominant (7) the happiest and to step 8 the least happy, as seen in Figure 6. The effect of contour was significant, F (3, 189) = 14.97, R^2 = 5.4%, $p < .001$, with rising melodic contours happier than falling ones in both the soprano and bass lines, as seen in Figure 7. And the step X contour interaction was significant, F (6, 378) = 4.99, R^2 = 2.5%, $p < .001$, in which contour had relatively little effect on step 8 in the middle of the happiness scale, but much more effect on steps 5 and 7 (see Fig. 9).

For the tension scale, the only significant effects were those of step, F (2, 126) = 17.67, R^2 = 4.2%, p < .001, and that of the step X contour interaction, F (6, 378) = 4.72, R^2 = 2.4%, p < .001, in which step 8 was clearly the tensest, and, as with the happy/sad scale, contour had relatively little effect on the ratings of step 8 (see Fig. 6).

The effects of the bright/dark and warm/cold scales were closely parallel, so we will report them together, with the statistical results provided in that order. The effects of modulation step were significant, F (2, 126) = 19.94, R^2 = 4.1%, p < .001; F (2, 126) = 13.52, R^2 = 4.2%, p < .001, and can be seen in Figure 6. The effects of melodic contour were significant, F (3, 189) = 17.49, R^2 = 5.7%, p < .001; F (3, 189) = 6.78, R^2 = 2.7%, p < .001, and can be seen in Figure 8. The interactions of step X contour, F (6, 378) = 5.08, R^2 = 2.6%, p < .001; F (6, 378) = 3.98, R^2 = 2.0%, p < .001, showed that, as with the other scales, the effects of melodic contour were the least for step 8 (See Fig. 9). And the interactions of step X training were barely significant, F (2, 126) = 3.13, R^2 = 0.6%, p < .05; F (2, 126) = 3.96, R^2 = 0.8%, p < .05, reflecting the generally stronger responses of the more highly trained listeners, especially to steps 5.

Insert Fig. 9 about here.

The results for the strong/weak and firm/wavering scales were also closely parallel, and will be reported in tandem. The effect of training was significant for strong/weak, but only approached significance for firm/wavering, F (1, 63) = 6.69, R^2 = 2.1%, p < .05: F (1, 63) = 3.42, R^2 = 0.8%, p < .07, and reflected a tendency for the more trained listeners to go for the stronger end of the scale. The effects of step were significant, F (2, 126) = 11.74, R^2 = 2.4%, $p < .001$; F (2, 126) = 4.13, R^2 = 1.1%, $p < .05$, and can be seen in Fig. 7. And the step X contour interactions were significant, F (6, 378) = 2.92, R^2 = 1.7%, $p < .05$; F (6, 378) = 2.47, R^2 = 1.6%, $p < .05$, and unlike the other adjective scales, showed the smallest effects of contour on the modulation to step 5.

In summary, the dominant was reliably recognized as the "happiest" step. Modulations to step 8 were perceived as most tense, whereas the close-proximity subdominant and dominant were not differentiated on the relaxed/tense scale. Progressions with simultaneous upward direction in the soprano and bass lines were generally heard as happier, brighter, and warmer than modulations with other contour patterns. However, affective responses to the distant step 8 were influenced relatively little by the melodic contour patterns, suggesting that there the influence of tonal distance was stronger than the influence of the melodic direction.

PCA for Real Music excerpts (RM)

A comparison of PCA graphs for the real music excerpts, considered just as three degrees of modulation, and harmonic progressions showed a similarity in the pattern of responses to the degrees of modulation (see Figures 7 & 9). However, there was an important difference in the orientation of dimensions for the adjective scales and thus a difference in identification of the principal components. For the harmonic progressions, the first two components were related to valence and potency, with tension in between, whereas for the real music excerpts the first component was tension-related (τ = 75.7%) and the second component (τ = 24.3%) was not aligned closely with any of the scales. The valence group and the potency group remained in the same relationship to the tense/relaxed scale as before, and generally orthogonal to each other. This indicates that perceived tension is the principal characteristic influencing affective responses to the real music excerpts, as compared to the harmonic progressions. For the real music excerpts, modulation to step 8 was felt to be the "tensest," and modulation to the dominant (7) was the most "relaxed." Modulation to the subdominant (5) was the "weakest." These results resemble those for the harmonic progressions, except that with real music the step 8 modulation was perceived more as tense and strong rather than tense but with negative valence, and the dominant modulation was perceived as relaxed and happy rather than relaxed and weak.

Insert Figs. 9 & 10 about here.

When the PCA was run on the whole set of 24 real-music modulations taken as individual instances a different clustering of adjective scales emerged explaining 92.6% of the variance (see Fig. 10). The first dimension was valence (τ = 80.1%) and was aligned with the happy/sad, bright/dark, and warm/cold scales; the second dimension was potency (τ = 12.5%) and now included the tense/relaxed scale. Here the listeners demonstrated surprisingly fine differentiation of musical styles: the Romantics appeared mostly on the negative side of the valence component, whereas Mozart and Haydn appeared on the positive side. It is important to note here that all stimuli in Experiment 2 were in a Major-Major condition, which means that the perception of the Romantics as darker and colder and unhappier than the composers of the First Viennese School indicates the influence of stylistic nuances. These nuances reflect the objective differences in textural and harmonic aspects of the Romantic and Classical music, as well as the first author' subjective details of interpretation related to the use of sustained pedal and intonation (agogica). Reponses to the excerpts from Schubert's music fell on both sides of the valence dimension, corresponding to Schubert's traditionally assigned position as bridging the style of the classical First Viennese School (Haydn and Mozart) and that of the Romantics (Beethoven, Chopin, Schumann, and Brahms).

The two strongest and tensest real music excerpts both represent modulation to step 8: an excerpt from Schumann's *Noveletten* (RS19, written in a low register), and an excerpt from Mozart's *Fantasia in C Minor* (M22, written in a high register). Among the four most relaxed and weak excerpts, three modulate to the dominant: the excerpts from Mozart's *Sonata in D major* (M12), from Haydn's' *Sonata in E-flat Major* (H15), and from Beethoven's *Sonata in c minor* (B16). The three "happiest" excerpts are all in fast tempo and relatively high register and they represent three different degrees of modulation: a subdominant step in Haydn's *Sonata in C Major* (H 2), a dominant step in Mozart's *Sonata in A Minor* (M 10), and step 8 in Schubert's *Sonata in B-flat Major* (FS 24). Fragments in a slow tempo—from Brahms's *Intermezzo* (JB 13), Schumann's "Vogel als Prophet" (RS 20), from Schubert's *Sonata in C Minor* (FS 8), and from Schubert's *Sonata in G Major* (FS 4)—were perceived as sad and dark. These fragments also represent different degrees of modulation.

Overall, the results demonstrated that tempo, musical style, degree of modulation, and tessitura influenced affective responses to modulations in the real music excerpts. The similarity of pattern of responses for the controlled progressions and real music in Experiment 2 showed that the affective influence of degree of modulation competes with the influence of other expressive aspects such as tempo, pitch range, pitch movement, and variations in articulation, texture, and dynamics.

ANOVA for Real Music excerpts (RM)

The data were subjected to a 2 levels of musical training X 3 steps of modulation X 6 adjective scales ANOVA in which training was the only between-groups comparison. There was a main effect of adjective scale, F (5,315) = 48.06, R^2 = 28.6%, $p < .001$, indicating the stronger responses to the scales relaxed/tense and strong/weak than to the other scales (see Fig. 10). The step X adjective scale interaction was significant, F (10,630) = 15.23, R^2 = 4.1%, $p < .001$, in which the different steps had different effects on the scales, as seen in Figure 9. And the interaction of step X training was significant, F (2,126) = 8.74, R^2 = 0.3%, $p < .001$, reflecting, as it did for the bright/dark and warm/cold scales for the harmonic progressions, the tendency of the more highly trained listeners to use more extreme responses on those scales than the less trained, for steps 5 and 7.

DISCUSSION

The results of Experiment 2 demonstrated that modulations to the distant step 8 were perceived as the "tensest" in comparison with modulations to the subdominant and dominant, both in the harmonic progressions and the real music excerpts. This is in agreement with the theoretical model of pitch proximity, as explained with the circle of fifths and with the results of Bigand et al. (1996). That the modulations to the subdominant and the dominant were reliably differentiated for the relaxed/tense scale in the real music excerpts but not in the harmonic progressions can be seen as corroborating evidence of the influence of expressive performances (versus non-expressive performances) on perceived key proximity (Thompson & Cuddy, 1997). In comparison with the rather monotonous harmonic progressions, the real music excerpts were richer in artistic cues, which could strengthen the sense of perceived key proximity. The results showed a greater variance in responses to the real music as compared with the harmonic progressions. The total sum of squares for the real music excerpts was 18% larger than for the harmonic progressions. A test for equal variance revealed that the difference in standard deviation across all conditions (SD = 1.26 for harmonic progressions versus SD = 1.37 for the real music excerpts) was significant: $F = 1.18$; $p < .001$; Levene's Test = L (1, 64) = 69.25; $p < .001$; $a = .05$.

Both in the harmonic progressions and the excerpts, modulations to the subdominant were recognized as "weaker" than modulations to the dominant; this finding resonates with the musicological research (Ribeiro-Pereira, 2004; Rosen, 1972). In the real music excerpts, a perceived increase in tension in modulations to the subdominant appeared in association with an increase in negative valence, so that modulations to the subdominant were recognized as "tenser," "sadder," "colder," and "weaker" and more "wavering" than modulations to the dominant. This finding complements studies in perceived key proximity that showed asymmetry of key perception in relation to the circle of fifths (Thompson & Cuddy, 1989, 1992, 1997). Whereas in the musicological research the notion of a "weaker" subdominant region is related to the larger-scale modulations that define the global structure of a musical composition, the present results revealed that the affective quality of the subdominant was sensed in brief modulating passages as well.

We also found an influence of contour patterns and an interaction between contour pattern and degree of modulation. Affective responses to modulations to step 8 were only weakly influenced by the melodic direction for the happy/sad and sensory scales (the ratings almost converge for happy/sad and bright/dark). In comparison, responses to modulations to the subdominant and dominant were clearly influenced by the melodic contour. This difference in responses suggests that the influence of key distance overpowered the influence of the direction of melodic contour in modulations to the distant step 8. The lesser level of perceived tension for the subdominant and dominant resulted in greater sensitivity to the contour patterns for the happy/sad scale and the sensory scales bright/dark and warm/cold. An increase in perceived tension for the rising soprano and rising bass in modulations to the dominant was associated with an increase in the ratings for all five other adjective scales—in a “happier,” “brighter,” “warmer,” “firmer,” and “stronger” direction.

GENERAL DISCUSSION

Perhaps the most important result that we found here was the association between perceived tension and affective characteristics, which emerged in Experiment 2 that used controlled harmonic progressions and real music. This association could have important implications for research in music perception because it connects emotions in music with the theory of tonal expectations determined by the interplay of tonal tension and release (Meyer, 1956; Lerdahl & Krumhansl, 2007) and with psychophysiological measurements of perceived tension (Fredrickson, 1995; Krumhansl, 1996; Madsen & Fredrickson, 1993; Nielsen, 1983; Toiviainen & Krumhansl, 2003).

The similarity in the pattern of responses to the controlled harmonic progressions and the much more expressive real music excerpts in Experiment 2 demonstrates that tonal modulation plays an essential role in determining affective responses to music.

Several of our findings confirmed previous investigations in tonal modulation. The greater perceived tension found in modulations to the distant step 8 (both in the real music excerpts and the progressions) as compared with the modulations to the near keys of the dominant and subdominant is in agreement with the results of Bigand et al. (1996) and Bigand and Parncutt (1999).

The found association of low tension in modulation in the clockwise direction on the circle of fifths for step 7, as contrasted with an increase of tension for counterclockwise motion for step 5 and step 8, complements previous investigations in perceived tonal tension (Toiviainen & Krumhansl, 2003) and perceived key distance (Thompson & Cuddy, 1989, 1992). The finding of a reliable differentiation between degree of perceived tension in modulation to step 7 and to step 5 for the real music excerpts, but not for the plain harmonic progressions, corroborated the results of the previous study by Thompson and Cuddy (1997) that demonstrated that the listeners' responses to expressive performance corresponded more closely to theoretical predictions based on the circle of fifths than their responses to nonexpressive performance. This advantage for real music excerpts might be related to a better short-term memory for expressively performed music (Tillmann, Dowling, Philippe, Molin, Schulze, Poulin-Charronnat, Schoen, & Bigand, 2013). It is possible that the richer artistic contents in the real music excerpts enhanced the memorization of preceding tonal information by generating a greater emotional response (Chapin, Jantzen, Scott Kelso, Steinberg, & Large, 2010; Vieillard, Roy, & Peretz, 2012), which amplifies the intuitive comparison between the opening and the concluding tonalities in modulation. In contrast to the previous research that found the primacy of valence and arousal for emotional response to music (Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005), responses to the target-steps of modulation for the real music excerpts showed that tension was the main dimension identifying the affective response (Figure 10). This discovery could be related to the above-discussed advantage provided by the greater artistic content of real music excerpts, which brought forth the main morphological principle of music—perceived tension (Lerdahl & Krumhansl, 2007).

Among new findings of our study was the influence of degree of tonal modulation on affective responsiveness to melodic direction. The responses to harmonic progressions showed the listeners' sensitivity to the contour patterns in modulation to the close steps 5 and 7 but not to step 8 (for the happy/sad scale and, to a lesser degree, for the sensory scales bright/dark and warm/cold) (Figure 10). These results suggest that an increase in perceived tension for the distant step 8 dampened the listener's sensitivity to the influence of melodic direction.

One of the interesting findings of our study was the listeners' perceptiveness of the problematic status of the modulation to the dominant step in a minor mode. The problem of ecological validity for modulations to the dominant in Experiment 1 arose from the powerful effect of the major and minor modes. Modulations to the dominant in the minor mode are not orthodox in classical functional harmony and are rare in classical music (see Figure 2). Most likely, the infrequent use of modulations to the dominant in the minor mode is caused by "flattening" the leading tone of the opening tonality. The leading tone is one of the main players in creating melodic intentionality. A flattened leading tone affects the very foundations of the tonal hierarchy that we are accustomed to, and this might create a feeling of discomfort. In contrast to the unpleasant feelings for the chromatic step 10, the positive responses to modulation to chromatic steps 1 and 8 could be linked to specific relationships between tonic triads of target tonalities, which are built on these steps, and the opening tonic triad. In a scale, chromatic tones are less stable than diatonic tones (Krumhansl & Kessler, 1982). Chromatic tones can be characterized as approaching semitones for diatonic tones. A qualitative and quantitative analyses of tonic triads of all available target tonalities revealed the importance of approaching semitones for producing positive-valence affective response for modulations to a chromatic step 1 and a diatonic step 11 in a major mode (Figure 8). For these modulations, the presence of three approaching semitones between the opening and the concluding tonic triads creates a sense of release from perceived tension (the "leading" kind of modulation). For modulations to a chromatic step 8 and a diatonic step 4, the positive-valence response is related to perceived stability that is attained by swapping of a tonic and a mode-defining third between the opening and the concluding tonic triads (the "pseudo-stability" kind of modulation—see Figure 4).

The infusion of harmonic context in modulation by means of separating two different tonic triads with several dissimilar chords, and thus creating a "prolongational structure" (Lerdahl & Jackendoff, 1983), allows us to measure affective responses to specific distances in tonal space (which we intuitively sense in terms of functional harmony (Holleran, Jones, & Butler, 1995) in a more natural environment than with the juxtaposition of the triads. Considering that melodic/harmonic communication in music is made of integration of immediate tonal relationships within the context of a given pitch set, research in modulation addresses the foundations of emotional responses for tonal music by exploring the basic elements of integration.

The participants' fine sensitivity to the rules of tonal harmony (such as the recognition of the most important and most popular target tonalities and the negative reaction to the ecologically problematic modulation to the dominant step in a minor mode) converges with other evidences showing implicit understanding of tonality and tonal music (Holleran et al., 1995; Tillmann, Bharucha, & Bigand, 2000; Brattico, Tervaniemi, Näätänen, & Peretz, 2006). Our results agree with the conclusions of the previous studies that the sense of functional harmony does not require explicit knowledge of the principles of tonal harmony but is due to casual exposure to music

A new and rather unexpected finding in our study was the refined sensitivity to musical style by the participants with no formal education in music theory and musicology. The grouping of responses to real music excerpts according to two different but close-in-time musical periods, Classical and Romantic, was already a quite interesting result, but the listeners' perception of Schubert's music as transitional between these two periods was a striking discovery. The perceptiveness to musical styles indicates that implicit musical expertise extends beyond the rules of tonal harmony and reaches the subtle cues provided by harmonic makeup (enriched by the use of a piano's sustaining pedal) and expressive timing, both of which are believed to be critical for differentiating historical periods in European musical tradition. This sensitivity suggests a broader reading of Leonard Meyer's ideas postulating that music perception is based on perceptual and cognitive expectancies. The found differentiation of musical styles by the listeners with no training in musicology emphasizes the primacy of perceptual aspect over cognitive processing.

Whereas our study did find the effect of moderate musical experience for the perception of tonal distance in modulation, the criteria for differentiating the participants on the basis of their moderate musical experience (four and more years of any kind of music making) was lower than in some other studies that compared music perception of highly trained musicians and those with no musical training. Overall, our findings of listeners' perceptiveness for different degrees of tonal modulation and for the dissimilarity of two musical styles that are treated as consecutive in musicology argue for the importance of intuitive mechanisms in music perception.

To explain music's directness in communicating emotions, we propose the *archaic model* of emotional processing, which connects perceived tension and neuroscience of affective response (Panksepp 1998, 2010). This model draws on the recognition of a strong precognitive aspect of music perception (Shewmon, Holmes, & Byrne, 1999; Panksepp & Bernatsky, 2002; Zatorre, 2005) and suggests that affective responses in music are generated by the intuitive integration of "gut-felt" sensations induced by the temporally organized levels of perceived tension. At the heart of archaic model is the concept of a virtual body image, or the "virtual self" within our paleomammalian brain, which integrates minute somato- and visceromotor responses to the environment (Panksepp, 2004). Relying on this concept, the archaic model of emotional processing proposes that the listener's minute sensations of differences in perceived tension acquire affective properties because the sequencing of these sensations in music mimics the way the "virtual self" reflects and integrates the experience of living. From this perspective, music can be explained as a sequence of tonal events that induce emotion by imitating the dynamics of the integration of somato- and visceromotor information in the midbrain. The integration of these sensations according to the tonal-temporal program of a particular musical composition results in the generation of a particular emotion. The gut-felt sensations are not emotions (Krumhansl, 1997); their artfully controlled sequences, however, can trigger emotional responses. The archaic model suggests that aesthetic emotion is built into musical composition as the “logic of emotion” (Langer, 1942/1957), employing the most primitive mechanism of reaction of the living organism to its environment, which is degree of physical tension. Listening to music activates in the listener the same simple mechanism of perceived tension, and this results in a “reconstruction” of a complex emotion.

The main point of our research in modulation was the relationship between tonal proximity and affective response. An explanation of music as melodic motion in the phenomenal space of tonal gravity emphasizes perceived tension as the main principle of melodic morphology and the dependence of affective response on tonal distance. Investigation of affective response to tonal modulation or tonal proximity addresses the primal source of emotion in music, which is the feeling about specific motion in tonal space. Learning about the perception of tonal modulation contributes important information to our understanding of music cognition and communicative properties of the art of music.

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Table 1

Classification of Twelve Target steps into Expected, Unexpected, and Ambiguous

Mode	Expected	Unexpected	Ambiguous
M-M	0,5,7	2,3,6,9,10	1,4,8,11
M-m	0,2,4,5,9	6,8,10	1,3,7,11
m-M	0,3,7,8	1,2,6,9,10	4,5,11
m-m	0,5,7	6,9,10	1,3,2,4,8,11
Total	15	16	17

Table 2

Degree of Modulation (in Semitones), Ordinal Number of the Pivot Chord, and Number of Different Chord Types in Each Modulation *

Degree of modulation	Pivotal chord number	Number of different chords
0	–	4
1	4	5
2	4	6
3	5	7
4	6	6
5	4	6
6	5	7
7	6	4
8	5	6/7
9	4	4
10	5	7
11	4	8

* For modulation to step 8 (an ascending minor sixth), the amount of different chords varied for the major and minor modes. All modulations consisted of 8 chord tokens.

Table 3

Potency Ratings (Strong/Weak and Firm/Wavering) for 12 Steps of Modulation and 4 Modal Conditions on a 6-Point Scale.

	Modal Condition			
	MM	Mm	mM	mm
Modulation Step:				
0	3.73	3.59	3.77	3.60
1	4.07	3.45	3.80	3.74
2	3.35	3.49	3.57	3.28
3	3.46	3.59	3.75	3.53
4	3.49	3.31	3.33	3.29
5	3.85	3.72	3.93	3.62
6	3.35	3.67	3.66	3.57
7	3.73	3.82	4.31	4.20
8	3.88	3.41	3.60	3.43
9	3.54	3.57	3.54	3.56
10	3.44	3.44	3.55	3.51
11	3.58	3.41	3.49	3.52

Table 4

Overall Ratings on the Combined Adjective Scales for Modulations in 4 Modal Conditions and 3 Expectancy Categories

	Modal Condition			
	MM	Mm	mM	mm
Expected	4.05	3.48	3.77	3.33
Unexpected	3.65	3.34	3.63	3.16
Ambiguous	4.09	3.32	3.90	3.27

Table 5

Ratings on the 3 Groups of Adjective Scales for the 3 Expectancy Categories and 4 Modal Conditions

	Modal Condition											
	MM			Mm			mM			mm		
Adjective Scales:	val	pot	ple	val	pot	ple	val	pot	ple	val	pot	ple
Expectancy:												
Expected	4.08	3.77	4.28	3.29	3.54	3.61	3.55	3.86	3.89	2.79	3.80	3.41
Unexpected	3.71	3.43	3.82	3.04	3.51	3.87	3.55	3.63	3.72	2.67	3.55	3.25
Ambiguous	4.25	3.75	4.28	2.93	3.57	3.45	4.08	3.58	4.05	2.97	3.46	3.37
Mean:	4.01	3.65	4.13	3.09	3.54	3.64	3.73	3.69	3.89	2.81	3.60	3.34

Key: val = valence scales: happy/sad, bright/dark
pot = potency scales: strong/weak, firm/wavering
ple = pleasantness scales: pleasant/unpleasant, warm/cold

FIGURE CAPTIONS

Figure 1. Tonal distance in terms of the circle of fifths. An increase in tonal distance between two tonalities brings new pitches (in red) into the opening pitch set. For the C major as an opening tonality, the G major represents a close modulation (adding only one new pitch) and the B major represents a more distant modulation (adding five new pitches). The smaller the number of pitches in common between the beginning and the concluding tonalities, the greater the tonal distance in terms of key proximity on the circle of fifths.

Figure 2. Distribution of modulations in 132 classical piano compositions. The y-axis shows the frequency of modulating fragments; the x-axis shows distance of modulations in semitones. These modulations were selected from the piano sonatas of Haydn, Mozart, and Beethoven, as well as from other collections of piano compositions by Beethoven (*Bagatelles*), Schubert (*Impromptus*), Schumann (*Humoresque*, *Kinderszenen*, *Kreisleriana*, *Arabesque*, and *Noveletten*), Chopin (*Ballades, Impromptus*), and Brahms (*Intermezzos*)

Figure 3. PCA for 48 Harmonic Progressions. The adjective scales happy/sad and bright/dark grouped themselves into the valence dimension (x-axis) whereas the scales strong/weak and firm/wavering formed the potency dimension (y-axis). The strongest variable commonality is related to modes. Target tonalities in the major (diamonds and squares) are all on the side with the positive connotations (happy, pleasant, bright, and warm), whereas target tonalities in the minor (triangles and dots) gravitate to the negative side (sad, unpleasant, dark, and cold).

Figure 4. The "leading" kind and "pseudo-stability" kind of modulation

Figure 5. Affective responses to Expected, Unexpected, and Ambiguous target-triads.

Figure 6. PCA for responses to modulations to the subdominant (5), dominant (7), and step 8 of the24 harmonic progressions (HP).

***Figure** 7*. PCA for responses to 24 harmonic progressions. Labeling: rising soprano/rising bass = triangles, falling soprano/falling bass = squares, rising soprano/falling bass = dots, falling soprano/rising bass= diamonds. Responses to modulations with rising soprano and rising bass are mostly on the positive-valence side (warm, bright, and happy), whereas responses to modulations with falling soprano and falling bass are mostly on the negative-valence side (cold, dark, and sad).

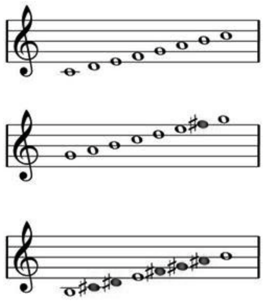
***Figure 8*.** Influence of melodic direction in the soprano and bass lines in harmonic progressions for the happy/sad and bright/dark adjective scales. The distant step 8 was only weakly influenced by melodic direction. Labeling: the first letter in each of four pair of letters indicates the direction in soprano line and the second letter indicates the direction in bass line so that 1RR = rising soprano line and rising bass line; 2RF = rising soprano line and falling bass line; 3FR = falling soprano line and rising bass line; 4FF = falling soprano and falling bass lines. (Whiskers show the standard error of the mean.**)**

Figure 9. PCA for responses to modulations to the subdominant (5), the dominant (7), and step 8 in the real music excerpts. The first component is defined by perceived tension.

Figure 10. PCA for responses to modulation in the 24 real music excerpts. Labeling: RS = Robert Schumann, FS = Franz Schubert, B = Beethoven, JB= Johannes Brahms, C = Chopin, M = Mozart, H = Haydn. The composers of the First Viennese

School fell mostly on the happy, bright, and warm side, whereas the Romantics were mostly on the sad, dark, and cold side.

Fig. 1



C major as the beginning tonality

The close tonality G major (**G**)

The distant tonality B major (**B**)

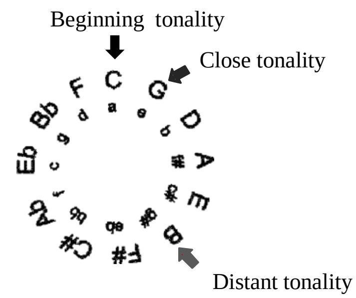
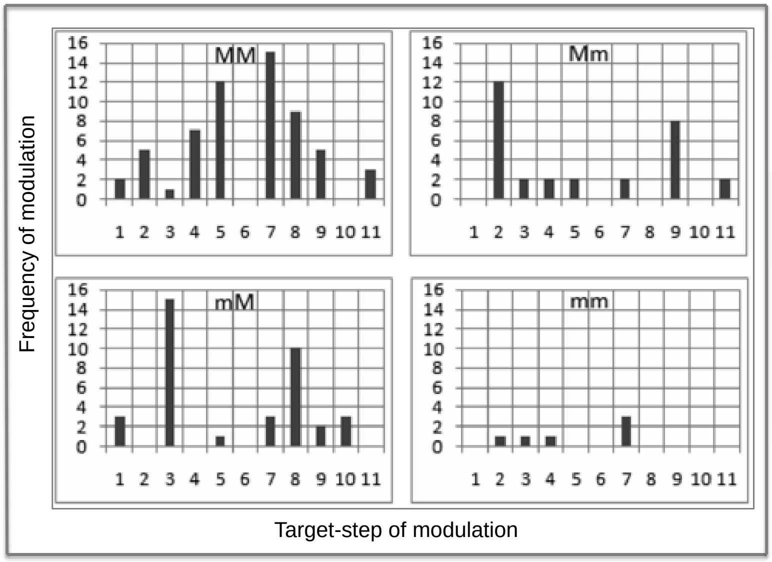
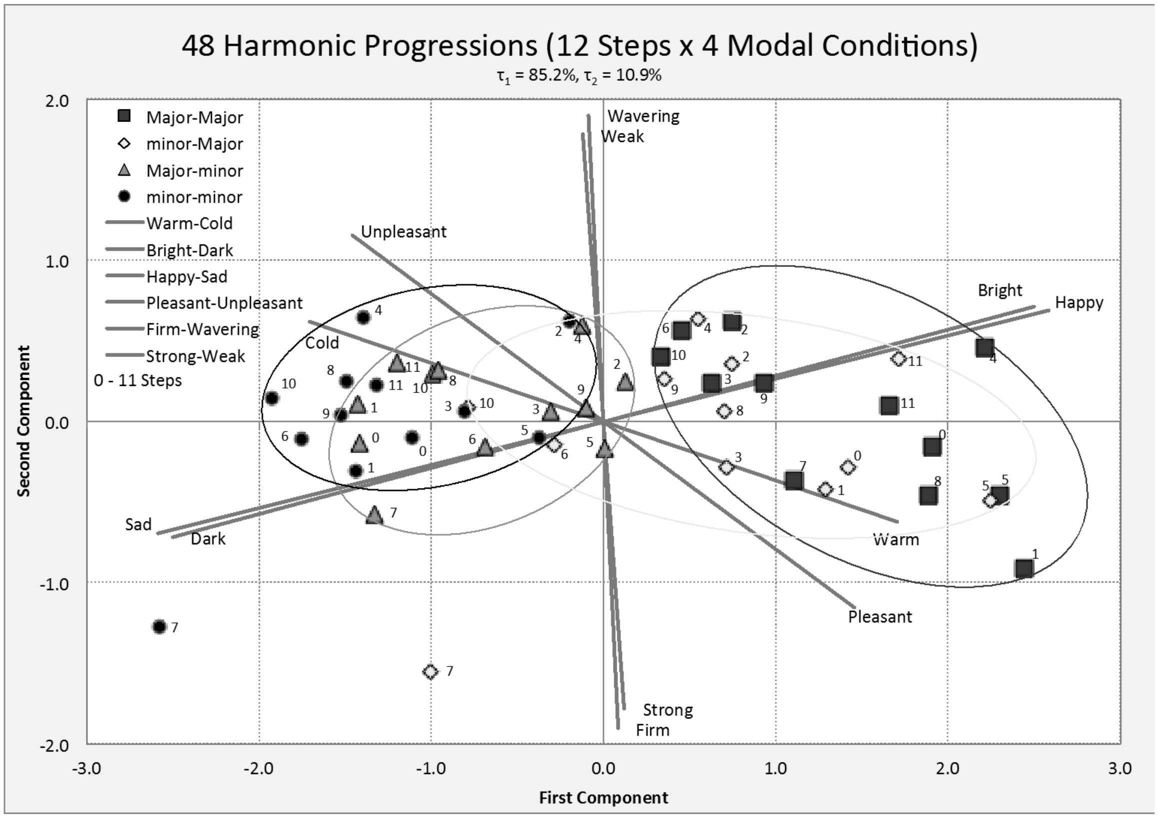


Fig. 2



MM
Mm
mM
mm
Frequency of modulation
Target-step of modulation

Fig. 3



48 Harmonic Progressions (12 Steps x 4 Modal Conditions)
τ1 = 85.2%, τ2 = 10.9%
Major-Major
minor-Major
Major-minor
minor-minor
Warm-Cold
Bright-Dark
Happy-Sad
Pleasant-Unpleasant
Firm-Wavering
Strong-Weak
0 - 11 Steps
Wavering
Weak
Unpleasant
Cold
Bright
Happy
Sad
Dark
Warm
Pleasant
Strong
Firm
Second Component
First Component

Fig. 4

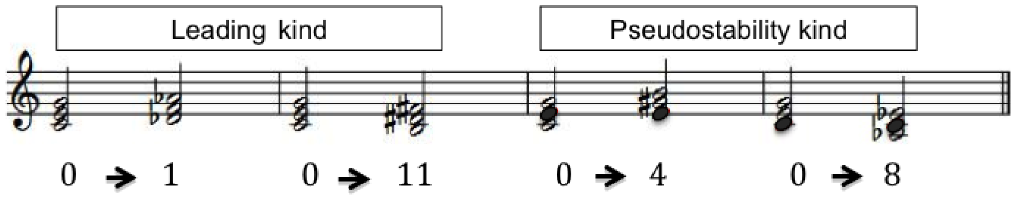


Fig. 5

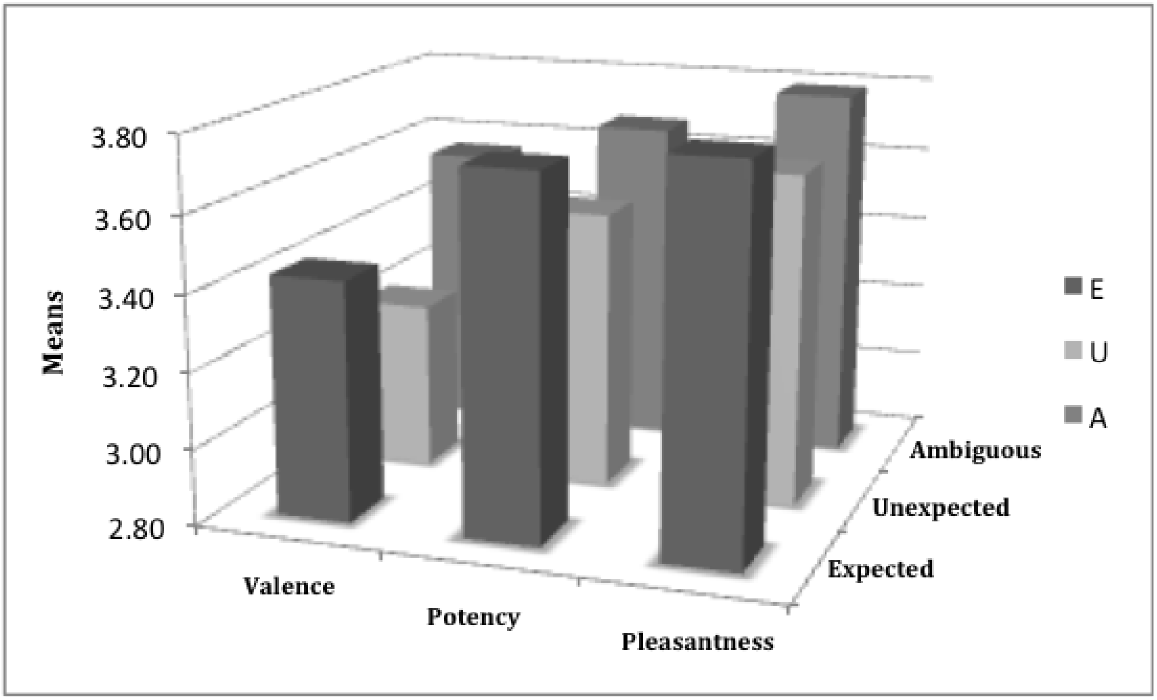
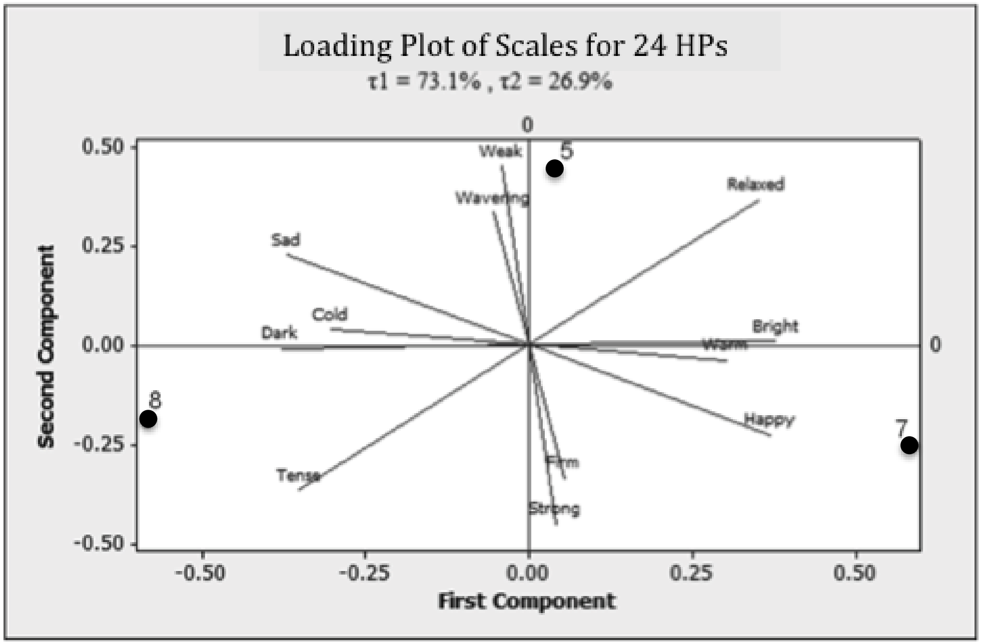

3.80
3.60
3.40
3.20
3.00
2.80
Means
Valence
Potency
Pleasantness
Expected
Unexpected
Ambiguous
E
U
A

Fig. 6



Loading Plot of Scales for 24 HPs
τ1 = 73.1% , τ2 = 26.9%
Weak
5
Relaxed
Wavering
Sad
Cold
Dark
Bright
Warm
8
Happy
7
Tense
Firm
Strong
Second Component
First Component
0.50
0.25
0.00
-0.25
-0.50
0.00
0.25
0.50
0

Fig. 7

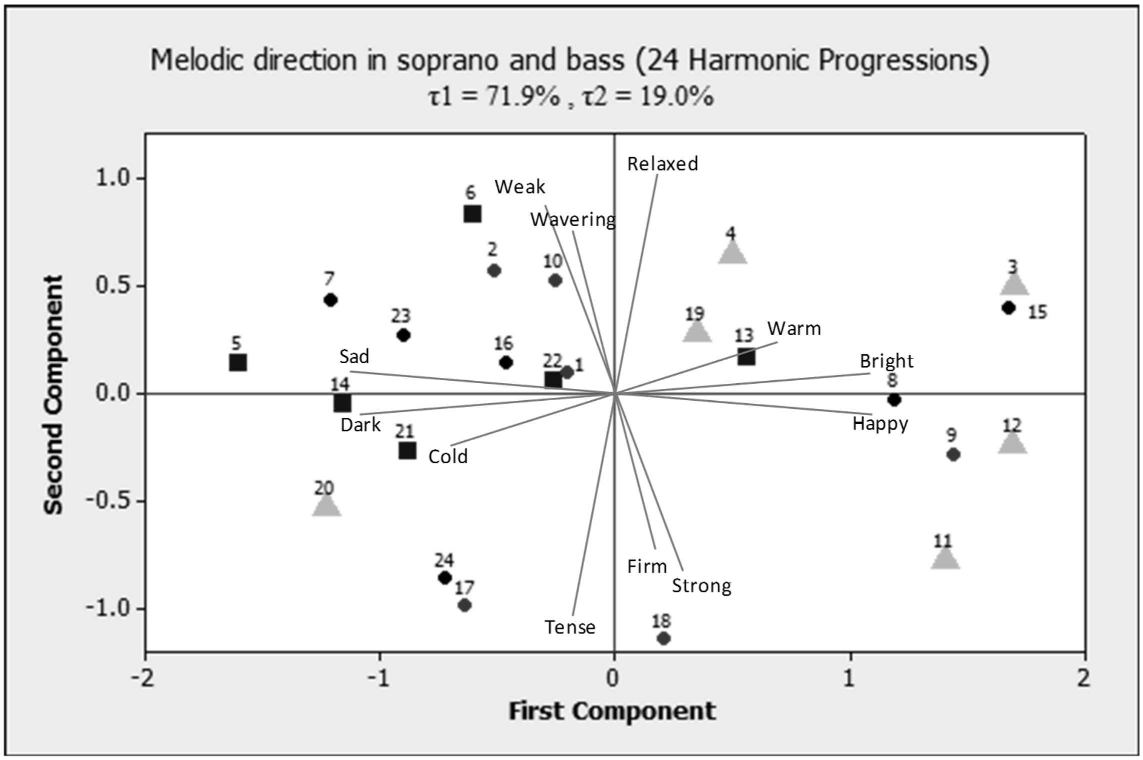
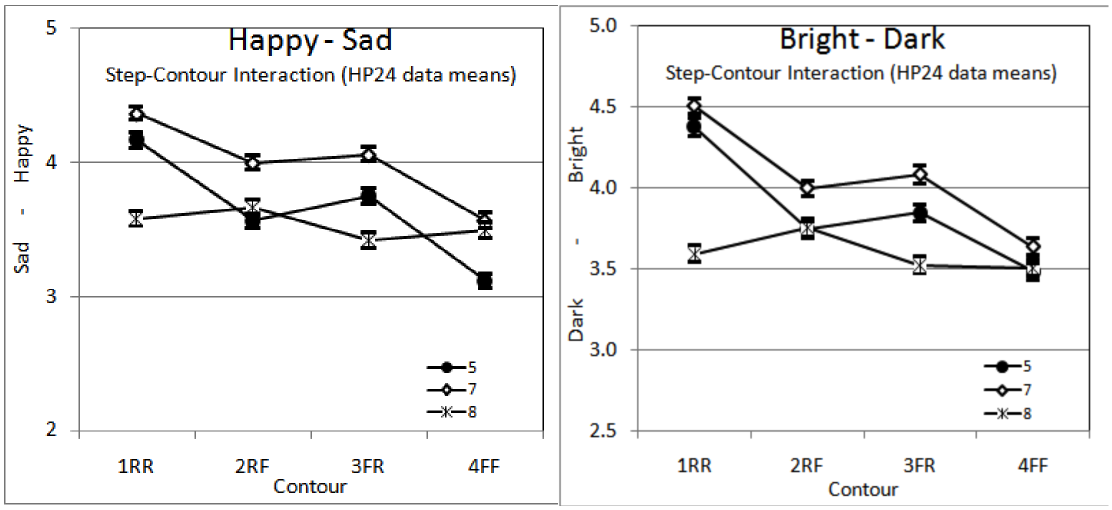

Melodic direction in soprano and bass (24 Harmonic Progressions)
τ1 = 71.9% , τ2 = 19.0%
Second Component
First Component
1.0
0.5
0.0
-0.5
-1.0
-2
-1
0
1
2
Relaxed
Weak
Wavering
Warm
Bright
Happy
Sad
Dark
Cold
Firm
Strong
Tense
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Fig. 8



Happy - Sad
Step-Contour Interaction (HP24 data means)
Sad - Happy
5
4
3
2
1RR
2RF
3FR
4FF
Contour
5
7
8
Bright - Dark
Step-Contour Interaction (HP24 data means)
Dark - Bright
5.0
4.5
4.0
3.5
3.0
2.5
1RR
2RF
3FR
4FF
Contour
5
7
8

Fig. 9

Loading Plot of Scales for 24 RMs

$\tau1 = 75.7\%$, $\tau2 = 24.3\%$

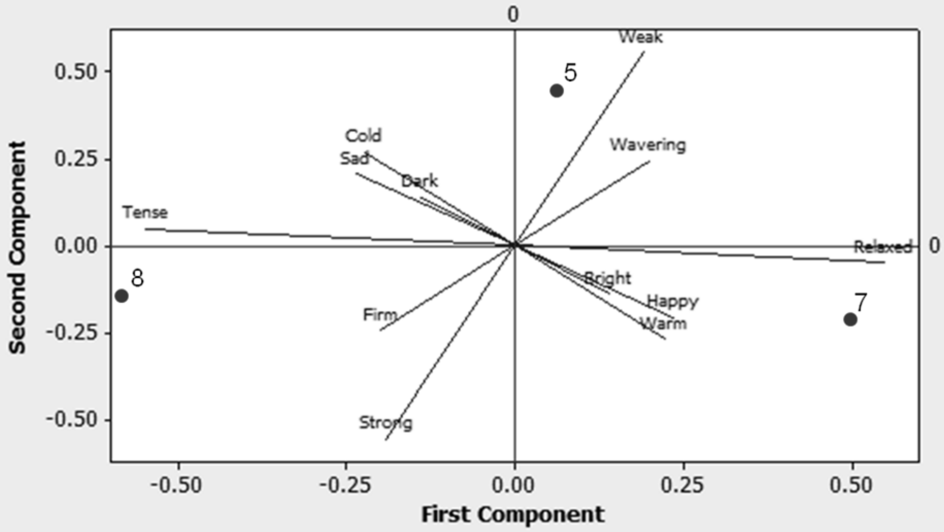
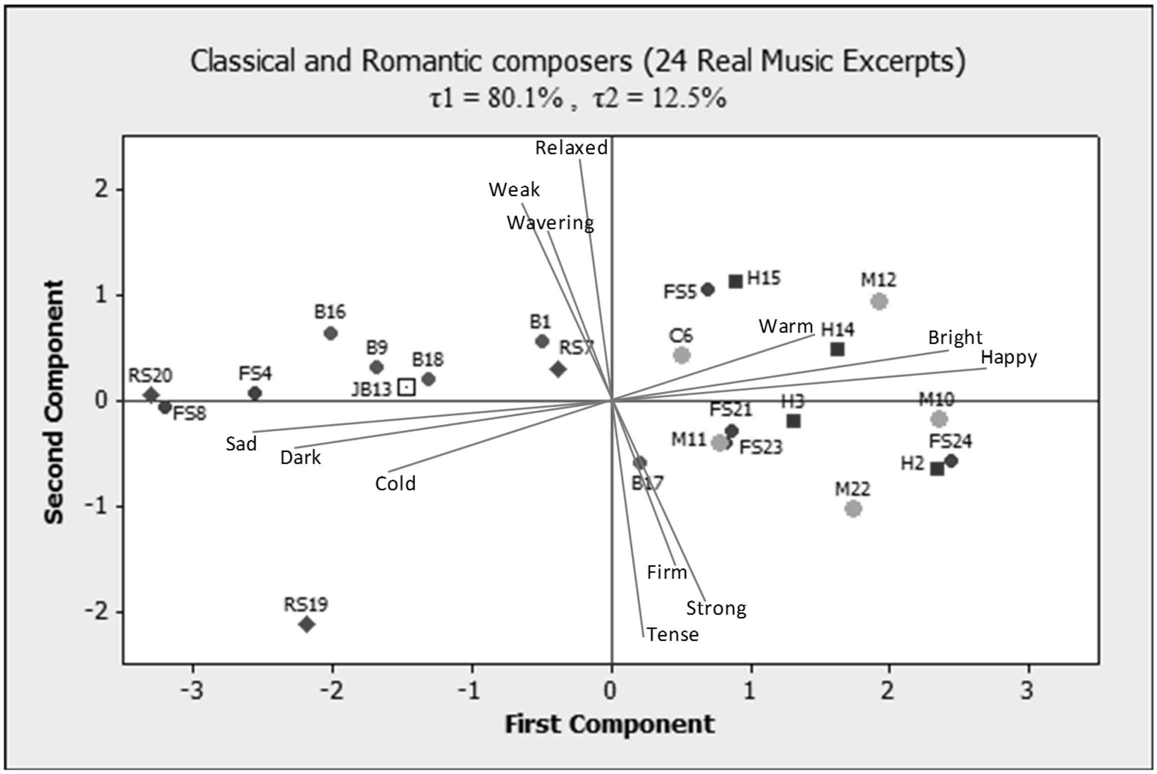


Fig. 10


Classical and Romantic composers (24 Real Music Excerpts)
τ1 = 80.1% , τ2 = 12.5%
Relaxed
Weak
Wavering
FS5
H15
M12
B16
B1
C6
Warm
H14
Bright
Happy
B9
B18
RS7
RS20
FS4
JB13
FS8
FS21
H3
M10
Sad
Dark
M11
FS23
FS24
H2
Cold
B17
M22
Firm
Strong
Tense
RS19
Second Component
First Component
2
1
0
-1
-2
-3
3

APPENDIX 1

List of real music excerpts for Experiment 2

Subdominant (5)

1. Beethoven, *Sonata No. 14, opus 27 (2), Allegretto,* A-flat – D-flat
2. Haydn, *Sonata in C Major, HOB. Xvi/35; l48, first movement*, C-F
3. Haydn, *Sonata in A Major, Hob. No. 5*, E-A
4. Schubert, *Sonata in G-Major, Opus 78, D 894, second movement*, D-G
5. Schubert, *Sonata in A-major, finale,* D-G
6. Chopin, *Fantaisie-Impromptu, opus 66*, A-flat – D-flat
7. Schumann, *Phantasiestucke, Fable*, opus 12, G-C
8. Schubert, *Sonata in c-minor, second movement*, A-flat – D-flat

Dominant (7)

1. Beethoven, *Bagatelles, opus 119, No. 4*, 64, A-E
2. Mozart, *Sonata in a minor, K. V. 300 (d), Presto (finale),* A-E
3. Mozart, *Sonata in D Major, K.V. 205, Var., XII,* D-A
4. Mozart, *Sonata in D Major, K.V. 205, Variations, Tema*, D-A
5. Brahms, *Intermezzo II, opus 118,* A-E
6. Haydn, *Sonata in C Major, No. 40 (Hob.), first movement*, G-D
7. Haydn, *Sonata in E flat Major, No. 49 (Hob.), Finale*, E-flat – B-flat
8. Beethoven, *Sonata No. 8*, Opus 13, Rondo (finale), A-flat - E-flat

Ascending minor sixth (8)

1. Beethoven, *Sonata No. 9*, opus 14, first movement, E-C
2. Beethoven, *Sonata No. 9*, opus 14, first movement, A-F

3. Schumann, *Noveletten, No. 4, opus 21*, A-F
4. Schumann, *Waldszenen, Vogel als prophet, opus 82*, G – E-flat
5. Schubert, *Sonata G-Major, Opus 78, D 894, Allegretto (finale*), G – E-flat
6. Mozart, *Fantasia in c minor,* F - D-flat
7. Schubert, *Waltz No. 14, Opus 9/a,* D-flat -A
8. Schubert, *Sonata in B flat Major, D960, Scherzo,* D-flat - A