CHAPTER 6
Tonal cognition

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THE term *tonal music* can be applied to a large variety of musical styles in the West. This includes that of the four periods (Baroque, Classical, Romantic, and Modern) into which Western art-music is commonly divided, as well as other musical styles from popular traditions such as jazz, rock-pop music, reggae, and salsa. Pieces from these musical styles sound so different that it can be difficult to realize that they share some of the same features. The most basic is that they rest on a single set of 12 pitch classes, referred to as the chromatic scale, *c, c#/d♭, d, d#/e♭, e, f, f#/g♭, g, g#/a♭, a, a#/b♭, b*.[1] These 12 notes are recycled every octave leading to a large number of musical tones. However, the number of pitch classes (12) remains low, (see Chapter 5 this volume for more detailed information about the difference between *pitch height* and *pitch chroma*). This set of pitch classes is organized in subsets of seven tones referred to as diatonic scales. The fact that so many styles in West rest on a low number of pitch classes organized in small subsets of seven notes highlights the combinatory nature of Western music. The purpose of this chapter is to focus on this combinatory aspect. What type of organization in the tonal pitch structure allows producing so many different styles, and so many different pieces inside each style?

In order to address this issue, we start by considering the theoretical distinction between 'tonal' and 'event hierarchies'. The main features of tonal hierarchies are then summarized and we consider how these hierarchies may be parsimoniously represented. The influence of tonal hierarchies on music perception is then reviewed. To conclude this chapter, we briefly consider how tonal hierarchies contribute, along with other musical parameters, to the definition of an event hierarchy specific to a given piece.

Tonal and event hierarchies in Western music

A critical feature of Western music is its hierarchical organization (Lerdahl and Jackendoff 1983; Meyer 1973; Schenker 1935). This is not to say that all structures in Western music are of hierarchical nature. Associative relations (between thematic cells, for example) also contribute to musical structure. However, the possibility of organizing musical events in a hierarchy of structural importance has deep implications for the listeners. A simple way to understand the concept of hierarchy is to consider that musical events are not all of equal importance: some are structurally important, while others are primarily ornamental. Ornamental events have aesthetic and expressive qualities but they do not contribute to the structure of the piece per se. Removing the ornamental notes does not alter the perceptual identity of a melody, while removing structural tones would modify the melody greatly (Dibben 1994; Mélen and Deliège 1995). If musical events were strictly of equal importance, pieces would sound like monotonous strings of sounds. By contrast, the presence of a hierarchy confers dynamic qualities on musical pieces that have powerful psychological implications: ornamental events seem to 'go towards' events of structural importance, which in turn tend to 'go towards' events

[1] For convenience, musical notes will be represented by lower case letters in italics and chords by upper case letters.

hierarchically more important, and so on across the extent of a piece.

Like linguistic discourses, music is a time-oriented structure that progresses from a beginning to an end. If the music stops at some point before the end, most listeners will realize that it has been irregularly interrupted (Bigand 1993; Palmer and Kruhmansl 1987). In a related vein, playing a piece backwards would strongly alter its perceptual identity because the dynamic relationships between tones would be reversed. Let us consider the set of tones *b-c-d#-e-f#-g*. This set of tones is perceived as a melody in the key of C major when played forwards but as a melody in B major when played backwards (Bharucha 1984). In the former case, the tones *b*, *d#*, and *f#* are perceived as ornamental tones anchored on the structurally important tones of the C major chord (*c-e-g*). Playing the tune backwards reverses the relationships between musical events, and the tones *g*, *e*, and *c* are now perceived as ornamental tones anchored to the structurally more important tones of the B major chord (*f#-d#-b*). This change in perceptual organization may be metaphorically compared with the change in meaning that occurs when a sentence is read in a retrograde way (the boy calls the girl *versus* the girl calls the boy). In the first sentence, *the boy* is anchored to the verb *calls*. In the second sentence, *the girl* is anchored to that verb. In language, the main aspect of syntactic computation is to understand 'who is doing what to who'. Similarly, the core aspect of tonal cognition is to perceive 'which tones anchor which tones'. Solving such a problem reminds us of syntactic computation, because musical events can be deeply anchored to the overall structure of the piece: a given tone can be anchored to another one, which may be, in turn, anchored to another one, and so on. Organizing the pitch events of a piece into a single coherent structure, in such a way that the pitch events are heard in a hierarchy of relative importance, is the most fundamental aspect of tonal cognition for Western music (Lerdahl and Jackendoff 1983).

Where do hierarchies between events come from? Two types of hierarchies have been distinguished in music cognition (see Bharucha 1984; Krumhansl 1990; Lerdahl 1989). The term 'tonal hierarchy' was used to designate an atemporal schema of pitch regularities, specific to Western music, which is stored in long-term memory (see Chapter 2 this volume). It embodies the hierarchical relations that accrue to an entire tonal system beyond instantiation in any particular piece. It is atemporal in that it represents more or less permanent knowledge about the musical system rather than a response to a specific sequence of events. Tonal hierarchies thus designate the regularities in pitch that prevail for all styles of tonal music. By contrast an 'event hierarchy' is a hierarchy of specific pitch–time events inferred from the ongoing temporal sequence of musical events. In the next sections, we will focus on tonal hierarchies however, in conclusion, we will briefly consider how tonal hierarchies influence event hierarchies.

Tonal hierarchies: intra-key hierarchies and inter-key distances

The main aspects of tonal hierarchies can be summarized in the following way. From a set of 12 pitches, several subsets of seven pitches are defined, each defining a musical key. A musical key is defined in reference to a specific tone which is called the tonic tone and that gives its name to the key. Since there are 12 tones, there are 12 possible tonics. In Western music, some subsets of tones form major keys. Others form minor keys. For example, the C major key is made of the following tones: *c-d-e-f-g-a-b*. The C minor harmonic key is made of the tones, *c-d-eb-f-g-ab-b*. In both cases, the pitch *c* is the tonic. Major and minor correspond to two different scales of pitch intervals. For example, the set of pitch intervals separating the tones of the C major key is tone-tone-semitone-tone-tone-tone-semitone. This set defines a scale that is constant for all major keys. In a minor harmonic key, the scale is different: tone-semitone-tone-tone-semitone-one tone and a half-semitone. Applying these major and minor scales to each tone of the chromatic scale defines 24 major and minor keys.

The critical aspect of the tonal pitch system relates to the organization of pitches within keys (referred to as intra-key hierarchies), and to the organization that exists between the 24 major and minor keys (referred to as inter-key distances). Kruhmansl and collaborators (see Krumhansl

1990, for a complete account) have investigated intra-key hierarchies with a 'probe tone' method, which consists of playing a test tone (the probe) after a musical context in a given key. Participants have to evaluate on a seven-point scale how the probe tone fits with the context. The 12 tones of the chromatic scale are presented as probe tones. It was found that all the probe tones did not received the same ratings of 'goodness of fit'. In major key contexts, the highest rating was given to the tonic note (the tone *c* in C major), followed by the fifth degree of the scale (*g*), and then the third degree (*e*), the fourth (*f*) and the remaining tones of the key (*d-a-b*). The tones that do not belong to the key (the 'non-diatonic tones'), received the lowest ratings. This set of values defined the C major key profile (Figure 6.1, top). The reader could easily obtain the profiles of all the other keys by translating these profiles to all the remaining tonics. As illustrated by Figure 6.1 (bottom), the ratings found when minor keys were used as context differed in an interesting way; the tonic remains the tone that fits the best with the key context, but then comes the third scale degree (*eb*), followed by the fifth and the sixth scale degrees (g and *ab*, respectively). The other diatonic tones received lower ratings, and the non-diatonic tones, the lowest. The minor key profile remains the same for all other minor keys but it has to be translated towards the tonic of the given key context. Important tones in these key

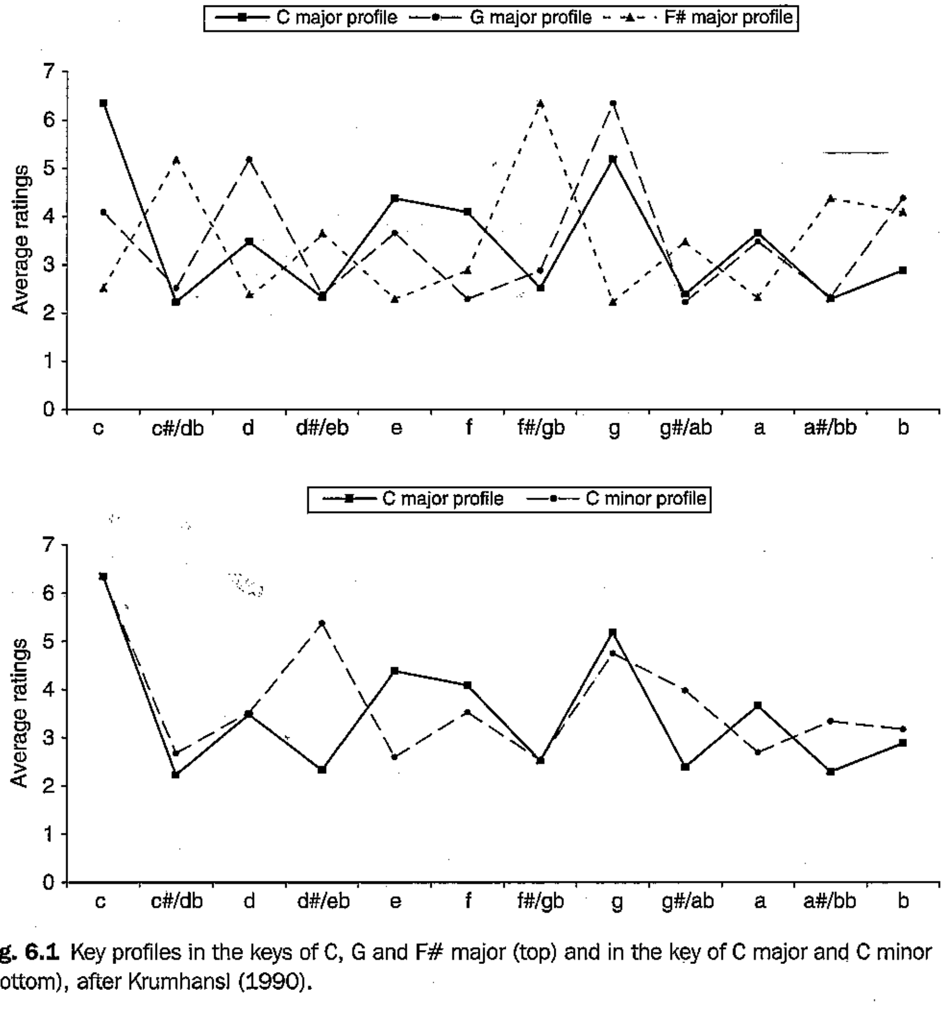

Fig. 6.1 Key profiles in the keys of C, G and F# major (top) and in the key of C major and C minor (bottom), after Krumhansl (1990).

profiles act as cognitive reference points that anchor all other events. In Western tonal music, the tonic is thus the most important cognitive reference point that anchors all the other tones (Schenker 1935).

Within a key, tones may be grouped to define larger musical units called chords. A chord is the simultaneous or sequential sounding of, at least, three different tones.[2] The three basic component tones of a perfect major or minor chord (also called a triad) are separated by one scale degree. For example, the C major triad is made of the tones *c-e-g*. The E minor triad is made of the tone *e-g-b*. The first interval defines the third of the chord. In a major chord, the third corresponds to a pitch interval of 4 semitones (*c-e*). In a minor chord, the third is made of a pitch interval of three semitones (*c-e♭*). The second interval defines the fifth of the chord. Since there are seven tones per scale, there are seven chords in each key, some being major, others minor, and others diminished.[3] Over all the keys, there are 12 major, 12 minor, and 12 diminished chords. Chords are important events for Western music: they define harmonic frames from which thematic units derive. Vincent d'Indy (1900) metaphorically compared the themes of a musical piece to the actions of a drama, and the relationships between chords to the places where the actions occurred. This points up the fact that the relationships between chords (i.e., the harmony) are of considerable importance in defining the structure of a given piece.

In Western music, the relationships between chords are also of a hierarchical nature; some chords are structurally more important than others. Using the probe tone method, Krumhansl *et al.* (1982) investigated the hierarchies between chords. Goodness of fit ratings varied significantly with the chords: in major key context, chords build on the first scale degree (referred to as the tonic chord) received the highest ratings, followed by the chords build on the fourth and fifth scale degrees (respectively referred to as subdominant and dominant chords). The other chords received lower ratings. Among all the major chords, those that did not belong to the key context received the lowest ratings. In other words, a harmonic hierarchy was found between chords.

The last main aspect of tonal hierarchies relies on the distance between the 12 major and 12 minor keys. Some keys share more tones and chords than others. For example, the key of C and G major share 6 tones and 4 chords, while the key of C major shares only 3 tones and no chord with the key of E major. These relationships are reflected on the chromatic circle of fifths (C-G-D-A-E-B-F#/G♭-C#/D♭- G#/A♭-D#/E♭-A#/B♭-F). The higher the number of steps between two keys, the fewer the common tones and chords shared by the keys. Major keys share also tones and chords with minor keys. For example, C major and A minor share six tones and three chords. The number of tones and chords shared by keys contributes to define musical distances between the keys, with keys sharing numerous tones and chords being closer than others.

From a psychological point of view, the musical distances between keys is more complex that this simple computation. Krumhansl (1990) demonstrated that the perceptual distance between keys is expressed by the correlation that exists between the hierarchical profiles of the keys: the higher the correlation, the closer the keys. This finding suggests that keys are not only related because they share several tones, but also because hierarchically important tones in one key continue to be of importance in others. The hierarchical organization of tones and chords thus changes less between two related keys than between two distant ones. For example, the keys of C major and C minor are musically related although they do not share many tones and chords (four tones, and no chord). However, in both keys, the notes *c* and *g* act as the two most important reference points which anchor the other tones. In a similar way, the key of C major is close to its relative minor key (i.e., A minor). Indeed, the tones *c* and *e* that are hierarchically important in the former key continue to act as referential points in the latter. As a consequence, every major key (C, for example) is close to two minor keys (its parallel and relative minor keys; C

[2] The sounding of two sounds defines an interval, not a chord. More complex chords contained additional tones. For example, the famous dominant seventh chord is made of the tones *c-e-g-b♭* in the F major key, and chords containing two or three ornamental tones are frequent in jazz and bossa nova (as in the major ninth chord *c-e-g-b-d*, or the minor ninth chord *d-f-a-c-e*).

[3] The C major key is made of the following chords: C major (*c-e-g*), D minor (*d-f-a*), E minor (*e-g-b*), F major (*f-a-c*), G major (*g-b-d*), A minor (*a-c-e*), and B diminished (*b-d-f*).

and A minor) and two major keys (those that are separated by one step on the circle of fifths: G and F major). Every major key is also indirectly close to the relative minor keys of the major keys that surround it (C major is close to E minor which is the relative minor of G major). The 12 major and 12 minor keys thus define a complex net of musical relationships (Figure 6.2, bottom).

Moving from one key to another results in a mental reorganization of the hierarchical values of tones and chords. This reorganization is as strong as the new key is distant from the previous one. These changes in cognitive reference points are experienced in an expressive way by listeners. Moreover, the expressive quality of a modulation (i.e., a change in key) is held to depend upon the distances between the two keys: the farther away the keys, the stronger the cognitive reorganization of reference points, and the stronger the expressive effect. As the 12 major and 12 minor keys define a complex net of keys, an almost infinite number of ways exists to modulate from one key to another and to express different feelings for/in listeners.

Two models of tonal hierarchies

Notes, chords, and keys define three levels of entwined structures that allow Western composers to invent an infinite number of expressive musical pieces. An important issue for cognitive psychology is to capture in a single parsimonious model the creative power of such a musical system. In the present section, we will consider two models of Western pitch structures that derive from different scientific backgrounds.

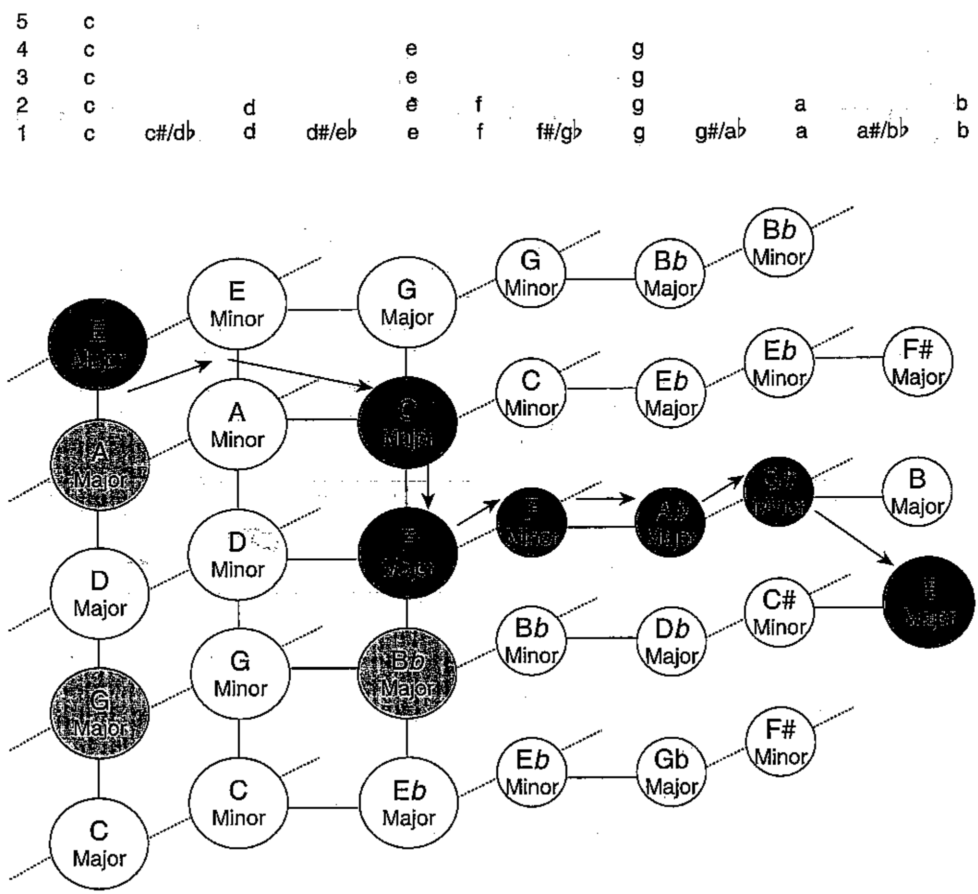

Fig. 6.2 Pitch class level (top) and regional level (bottom) of Lerdahl's tonal pitch space theory. The arrow illustrates the journey through pitch space of Chopin's E major prelude (adapted from Lerdahl 1991).

The Tonal Pitch Space Theory (TPST), initially described by Lerdahl (1988) and further developed in Lerdahl (1991, 1996, 2001) rests on a long tradition of representing the structure of Western music as a multidimensional space (Longuet-Higgins 1978; Krumhansl 1990; Shepard 1982). In such an approach, tonal hierarchies are represented in a space so that the distances between tones and chords from the instantiated tonic correspond to their relative hierarchical importance: the smaller the distances from the tonic, the stronger the importance. Lerdahl's TPST provides a formal means of quantifying the tonal distances maintained between any two events belonging to any key. Tonal hierarchy is represented in three embedded levels, the first two (pitch class and chordal level) representing the intra-key hierarchy, while the third (regional level) represents the distance between keys. The pitch class level expresses the relationships between the 12 pitch classes. It contains five sublevels corresponding to the chromatic level (1), the diatonic level (2), the triadic level (3), the fifth level (4) and the tonic level (5) (Figure 6.2, top). This basic space expresses Krumhansl and Kessler (1982)'s key profiles of Figure 6.1. In a given context (say, a C major chord in C major), the tonic tone (*c*) will be represented at all five levels. The dominant and the mediant tones (*g* and *e*) will be represented up to levels four and three, respectively. The diatonic tones are represented at level two and non-diatonic tones are represented at level one only. The level at which a given pitch class is represented thus expresses its importance in the tonal hierarchies of the key context. Hierarchies between pitch classes change as a function of context. For example, a C major chord in G major will produce a single change in pitch class (the f# will be now represented at level 2 and the f at level 1). The core idea of TPST is to quantify the tonal stability of each event (i.e., its place in the tonal hierarchy) by computing the number of changes in pitch classes it introduces in the context.

Let us consider the second level of the model, which involves the hierarchies between chords within a given key. The hierarchical values of the chords depend upon their distance to the tonic. This distance is measured in the model by the number of steps that separates the chords on the diatonic circle of fifths (C-G-D-A-E-B-F) and the number of changes in pitch class created by the second chord. In C major, the G major chord stands one step apart from the C major chord on this circle, and it creates four changes in pitch classes by reference to the C major chord. As a consequence, its distance to the tonic chord equals five. Similarly, the tonal pitch space distance of the subdominant chord (F) is five, but the distance of the other chords, hierarchically less important, is higher (e.g., eight for the supertonic chord D minor). These distances express the local changes in hierarchies between tones that prevail when music moves from one chord to another. These changes are experienced by listeners as musical tensions (when the distance increases), or as musical relaxations (when the distance decreases) (Bigand *et al.* 1996). The set of distances traveled through pitch space by a musical sequence thus captures the dynamic quality of the sequence.

The two previous levels would suffice to account for intra-key hierarchies. The third level (regional level) deals with the distances between the 24 keys. The model accounts for key distances by measuring the number of changes in hierarchies between tones and chords consecutive to a shift towards a new key. Not surprisingly, the TPST computes small distances between keys that are one step apart on the chromatic circle of fifths (C, G, and F, for example, which have a distance of 7) and between keys that are related according to parallel and relative minor/major relations (C and C minor, C and A minor). The greatest distance computed by the TPST (30) is found between a given key and its augmented fourth key (C and F# major keys). The distance between two chords belonging to different keys depends upon the way the two chords are interpreted. Given that chords may belong to different keys, this distance can be reduced when the two chords are interpreted as chords of closely related keys. For example, the distance between a C major chord and a C# minor chord equals 30 if the latter chord is analysed as the tonic chord of the C# minor key. The same distance equals 23 if the C# minor chord is analyzed as a member of the E major key. By default, the model would compute the shortest distance. Figure 6.2 (bottom) illustrates how the 24 keys may be organized in a two-dimensional space. Circle of fifth relationships are represented on the vertical axis, and parallel/relative minor/major relationships are represented on the horizontal axis. Modulating to G, F, E, or C minor from the C major key would result in smaller movements than modulating to a musically less related key (e.g., A♭).

Lerdahl suggests that listening to music corresponds to a journey through pitch space. The arrows of Figure 6.2 illustrate a journey provided by the Chopin prelude in E major. The first part of the prelude remains in E major, with local movements from one chord to another. The second part introduces an intense journey from E to the A♭ major and a fast return to the main key of E. There seems no doubt that the expressive quality of this prelude comes from the velocity at which this journey from E to A♭ occurs during the second phrase (Bigand 2003). The TPST is a musical model of tonal hierarchies that has both theoretical and empirical roots, and that has received support from several empirical studies (Bigand and Parncutt 1999; Bigand *et al.* 1996; Krumhansl 1996; Lerdahl and Krumhansl 2007; Smith and Cuddy 2003; Vega 2003). The TPST is helpful in investigating challenging assumptions about tonal cognition and it has a number of psychological implications (see Bigand 2003). However, it may be viewed as a rather ad hoc complex model, difficult to implement in an automatic way in an artificial system, and of which the architecture is too abstract, as it stands, to correspond point by point to real cognitive processes.

An alternative account of tonal hierarchies that has roots in cognitive psychology and computational sciences has been proposed by Bharucha (1987). Following McClelland and Rumelhart's interactive model of lexical access (McClelland and Rumelhart 1981; Rumelhart and McClelland 1982), Bharucha defines a three-layer interactive model that links tones, chords, and keys. In this model, tone units are connected to all major and minor chords to which they belong (Figure 6.3a). These chords are, in turn, linked to each of the major key units to which they belong. An important musical limitation of the model is that only major and minor triads are represented, and that the model does not contain minor keys. However, the model captures interesting features of tonal hierarchies. For example, when a given triad is sounded (say the tones *c-e-g*), the activated tone units send activation towards all the chord units to which they are connected (Figure 6.3b). At the second iteration, these chord units propagate activation towards the keys to which they are related, and backward to the tones they are connected to (Figure 6.3c). As a consequence, tone units that were not in the stimulus start to be activated. For example, the tone *a* receives some activation from the F and A major chords and the A minor chord that were stimulated by the tones *c* and *e*. At the third iteration, these new activations of the tones propagate towards the chord level. At the same time the activation of the key level spreads backward to the chord units (Figure 6.3d). Since the C major key was active, all the chords of the C major key now start to be stimulated. During the next iterations, all of these activations spread backward and forward up to a point of equilibrium where spreading activation is so small that it does not change the overall state of the network. The interesting point is that this model of MUSical ACTivation (MUSACT) nicely expresses tonal hierarchies. For example, after a C major triad, the most activated chord units correspond to the tonic chord (C), the dominant and subdominant chords (G and F). The activations decrease progressively as long as chords are musically distant from the C major chords. The pattern of activation found for the key units also reflects the inter-key distances. For example, after a perfect cadence in the C major key, the C major key unit is the most activated unit, and this activation decreases as a function of the musical distances from the C major key.

In this model the knowledge of tonal hierarchy is expressed by the pattern of activation that spreads automatically towards tone, chord, and key units. Closely related events lead to a highly correlated pattern of activation, distant events, to negative correlations. In a given context, the amount of activation found for each unit (tones or chords) represents their hierarchical importance in the context. MUSACT thus captures features of tonal hierarchies that are strongly similar to those accounted for by Lerdahl's TPST, but with a completely different architecture. In MUSACT, the tonal hierarchies are represented in a distributed way by the weights of the connections that link tones to major and minor chord units, and chord units to key units. The specific values of these weights were defined ad hoc in the pioneer work by Bharucha (1987),

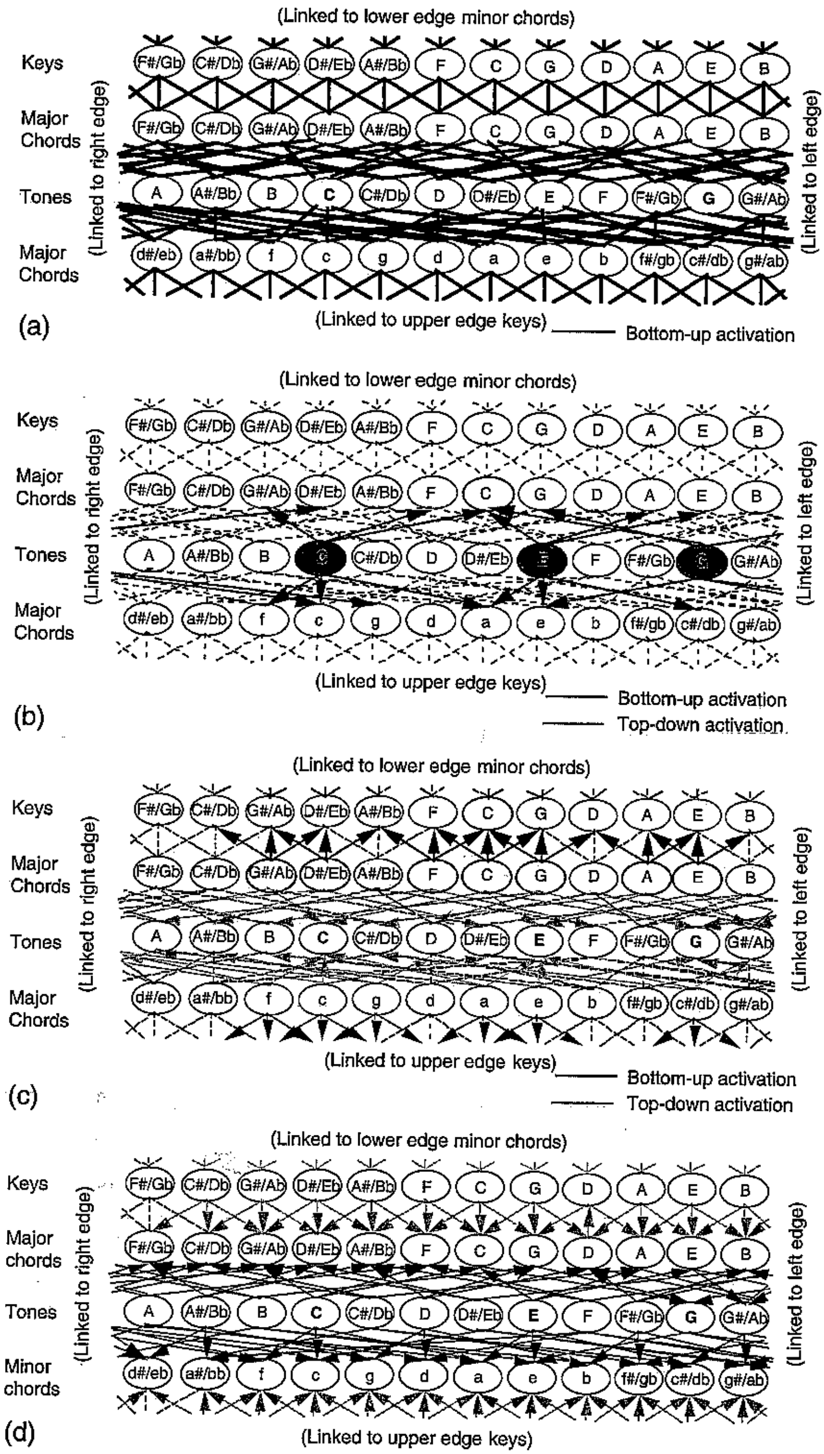

Fig. 6.3 Bharucha's MUSACT model. (a) When three tones are sounding, activation spread from tones to chord units (b), and then from chord to key and tone units (c), and from key units to chord and from tone to chord units (d) and so on up to equilibrium. See also colour plate section.

but it has been demonstrated that these weights may arise from a learning process that occurs automatically when the neural network is exposed to Western music (Tillmann *et al.* 2000).

Influences of tonal hierarchies on Western music perception

Much evidence has been collected demonstrating the influence of tonal hierarchies on music perception. For example, Francès (1958) required musicians to detect mistuned notes in piano pieces. This mistuning was performed in different ways. In one condition, some musical notes were mistuned in such a way that the pitch interval between the mistuned notes and those that anchored them was reduced. For example, the leading note (*b* in C major) which is hierarchically weakly important is generally anchored by the tonic note (*c* in C major). Francès mistuned the leading tone by increasing its fundamental frequency (F0) so that the pitch interval between the leading tone and the tonic was reduced. In the other experimental condition, this mistuning was performed in the opposite way. When played without a musical context, participants easily perceived both types of mistuning. Placed in a musical context, only the second type of mistuning (which conflicted with musical anchoring) was perceived. This outcome shows that the perceptual ability to perceive the shift of the F0 of a musical note is modulated by top-down processes that integrate the note into tonal hierarchies. More generally, performers such as violinists or cellists constantly adjust the fundamental frequency of the tones in order to make as clear as possible the way in which these tones are anchored by the hierarchically important tones of the context. This expressive intonation, which is entirely related to the tonal hierarchy, considerably increases a listener's comprehension of the musical discourse.[4]

Tonal hierarchies also influence the perception of melodic contour. Several experiments demonstrate that discriminating a small change in a contour is more difficult when the standard and the comparison melodies are in distant, rather than close, keys (Dowling 1986). Several experiments run by Krumhansl and collaborators (see Krumhansl 1990) demonstrate the influence of tonal hierarchy on the perceptual distance of tones and chords and on their memorization. This influence can be summarized in terms of three contextual principles. The perceptual distance between two events (tones or chords) increases when these events are of hierarchical importance (contextual distance). The perceptual identity of two instances of a given event increases with its hierarchical importance (contextual identity). Two occurrences of the chord C would sound more similar if they occurred in a C major key context rather than in a distant key context (say, in an F# key context). Finally, the perceptual distance of two events depends on their sequential occurrence: the distance decreases when the hierarchically strong important event occurs after the other one (i.e., anchoring principle). It increases in the other case (contextual asymmetry). Krumhansl and collaborators demonstrate that these principles account for confusion errors in memory. For example, it is easier to detect that two occurrences of a seven chord sequence are identical when these chords belong to a single key (diatonic sequence; 69.3 per cent) than when they belong to different keys (55 per cent), illustrating the principle of contextual identity. When the second occurrence of the sequence contains a different chord, it is easier to detect the difference when the chord is changed for a chord belonging to another key than when it remains in the same key (86 per cent *versus* 56.9 per cent). This illustrates the principle of contextual distance. Finally, when the initial sequence is diatonic and the comparison sequence contains a non-diatonic chord, the change is easier to detect (86.8 per cent) than when the first sequence contains a non-diatonic chord that is replaced in the second sequence by a diatonic chord (61.3 per cent). This illustrates the principle of contextual asymmetry.

The influence of tonal hierarchy on the memorization of melody may be very impressive. In one experiment (Bigand 1997), participants were required to listen several times to a target melody

[4] The reader would find a remarkable demonstration of such expressive intonation in Casals' performances of the cello suite by Bach.

Fig. 6.4 Examples of standard and comparison melodies used in Bigand (1997).

such as the melody in A minor represented in Figure 6.4 (top). Participants were then presented with new melodies and were asked to evaluate how many pitches had been changed in comparison to the standard. Figure 6.4 (bottom) displays one of the comparison melodies used. As can be seen, it contains most of the tones of the standard. Only a few tones have been changed in order to instill the key of G major at the beginning of the melody. This new key context was assumed to modify the hierarchical weights of the melodic tones. Indeed, the *a* is no longer a tonic tone in this comparison melody, but a weakly important supertonic tone. The reader is invited to use the key profiles of Figure 6.1 to understand how much the hierarchical weights of the tones have been changed in the comparison melody. Not surprisingly, the participants (musically trained and untrained listeners) evaluate that about 66 per cent of the tones have been changed in the comparison melody, that is to say, much more than what has actually been done.

The influence of tonal hierarchies has been reported in several other studies in which participants were asked to evaluate the degree of completion or the degree of musical stability experienced at different points of a musical sequence. Ratings of completion or musical stability were higher when the music stopped on hierarchically important events (Bigand 1993, 1997; Palmer and Krumhansl 1987). A similar result was found for chord sequences (Bigand and Parncutt 1999; Bigand *et al.* 1996). In recent studies, a continuous measure of musical stability has been used, and data were found to correlate significantly with tonal hierarchy (Krumhansl 1996; Lerdahl and Krumhansl 2007). Other studies have investigated the influence of tonal hierarchies on the speed at which some musical features are processed. In Bharucha and Stoeckig's (1986) chord priming experiments, the participants were required to decide accurately but as fast as possible whether a target chord was in tune or out of tune. For the purpose of the experiment one component tone of the chord was slightly mistuned in half of the trials. The target chord was preceded by a chord prime. The critical point of the study was to assess whether the processing of the sensory consonance of the target chord would be modulated by the harmonic relationship of the two chords. The authors provided evidence that consonant target chords were more accurately and more quickly identified as consonant when they were preceded by a related prime (e.g., C and G chords) than by an unrelated prime (e.g., C and F# chords). An opposite finding was found for dissonant targets. Bharucha and Stoeckig argued that a given context primes the processing of chords that are musically related in the context, a finding which is reminiscent of semantic priming effects reported in language (McNamara 2005). Further experiments attempted to demonstrate that this priming effect in music occurs at a cognitive level and does not result from the overlap in harmonic spectra of both chords (Bharucha and Stoeckig 1987; Tekman and Bharucha 1998).

The influence of tonal hierarchies on perceptual expectancy in long musical contexts has also been investigated with the priming paradigm (Bigand and Poulin-Charronnat 2006, for a review). In our experiments, participants were presented with chord sequences (of 8 or 14 chords depending on the studies) that ended on a target chord. The target acted either as a tonic or as a subdominant chord depending upon the context. The chord preceding the target was always kept constant, except when the local and global harmonic contexts surrounding the target were simultaneously manipulated (Tillmann *et al.* 1998). In most of the studies, participants were required to indicate as quickly and as accurately as possible whether the target chord was consonant or dissonant. Dissonant targets contained a supplementary tone, a half tone above or below a triadic tone. In more recent studies, target chords were played with two different timbres which participants had to identify as fast and accurately as possible (Tillmann and Lebrun-Guillaud 2006). Processing the sensory consonance of the target or its harmonic spectra was always faster and easier when the target acted as a hierarchically important tonic chord. This effect is extremely robust since it has been replicated for relatively long chord sequences organized at three hierarchical levels (Bigand *et al.* 1999), for normal and scrambled musical sequences (Tillmann and Bigand 2001), for chord sequences that have extremely poor voice leading (Poulin-Charronnat *et al.* 2005a), and even when sensory priming was manipulated in order to favour the subdominant target (Bigand *et al.* 2003). Harmonic priming was also found to be stronger than repetition priming (Bigand *et al.* 2005), and to modulate the processing of linguistic information in sung music (Bigand *et al.* 2001; Poulin-Charronnat *et al.* 2005). Finally, it was observed for musically trained and untrained listeners (Bigand and Poulin-Charronnat 2006, for a review), as well as with young children (Schellenberg *et al.* 2005). This large set of consistent data highlights the strength of tonal hierarchies on the formation of musical expectancies.

It is likely that tonal hierarchies influence several other aspects of music perception. In one recent study, we investigated how the tonal hierarchy influences emotional responses to music (Filipic and Bigand 2003). Participants were required to decide as fast and as accurately as possible whether two musical sequences expressed the same or different emotion. Musical sequences that were qualified as either sad or serene in Peretz *et al.*'s (1998) studies were used and the participants were informed that all stimuli fall into one of these two emotional categories. In half of the trials, the musical pieces were in the same keys. In the other half they were in distant keys. We found that emotional responses were faster and more accurate when both pieces were in the same key. This finding suggests that interpreting the tones in a tonal key context is a prerequisite for the recognition of the emotional value of the stimuli.

From tonal hierarchies to event hierarchies

The critical importance of the tonal hierarchy is to contribute to instilling an event hierarchy specific to a given piece. As formalized in Lerdahl and Jackendoff's Generative Theory of Tonal Music (1983), the tonal hierarchy provides the stability conditions that need to be integrated into rhythmic parameters (notably) in order to define the structural importance of each tone of the piece. The structural importance of a musical event thus depends upon its place in

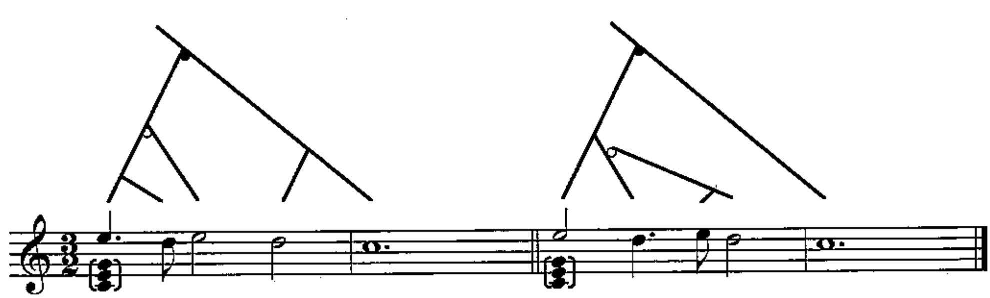

Fig. 6.5 Influence of tonal hierarchies and rhythm on event hierarchies. Inspired by Lerdahl and Jackendoff (1983) with the help of the first author.

tonal hierarchy and the rhythmic context in which it appears. A tonic note of a given melody would not always act as a structurally important tone. Depending upon the group of tones in which it appears as well as its duration and its metrical position, a tonic note may act as an ornamental event in the event hierarchy. Modifying the rhythm of a set of tones is enough to change the event hierarchy as expressed in the following example (Figure 6.5). The *e*, which is an important tone in the C major key context, may act as an important anchoring tone in some rhythmic contexts (Figure 6.5 left) but not in others (Figure 6.5 right). This point is most crucial as it means that the tonal hierarchy is considerably modulated by numerous other musical parameters such as rhythm, loudness, and timbre. These parameters are adjusted by the composer and the performer in numerous ways, leading to a quasi infinite number of possible event hierarchies. The combination of tonal and event hierarchies creates a great unity in a quasi-infinite variety of Western musical pieces.

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