A Review of Carol L. Krumhansl's
Cognitive Foundations of Musical Pitch*

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The psychology of music perception and cognition, nearly dormant 15 years ago, has made considerable strides in the last decade. Several textbooks and edited collections of articles have appeared, two new journals have been established, societies have been formed, and many reports of empirical studies have been published, including one in monograph form (Serafine, 1988). However, the field is still new and small, and few researchers have had the persistence and the good fortune of continuous grant support to develop and bring to fruition an extended and coherent program of research. Carol Krumhansl, of Cornell University, has accomplished that feat, and her monograph documents a decade of individual achievement, resulting in a critical mass of psychological data organized in a tight conceptual framework. This publication is a landmark event in a young field striving for definition and recognition.

The brilliance of Krumhansl's approach was recognized early on by her peers who bestowed on her the American Psychological Association's Distinguished Scientific Award for an Early Career Contribution in Psychology (see American Psychologist, March 1984, pp. 284-286). The citation honored her for "a dazzling interplay of experimental techniques, music theory, and multidimensional scaling" that had uncovered "new cognitive structures of great richness and beauty" (ibid., p. 284). This methodological virtuosity as well as its satisfying results are evident throughout the book. Although nearly all the results have been published previously in accessible journals, they are brought together here for the benefit of the reader, who is led through the complex issues by lucid explanations and discussions. The clear organization and sense of direction make reading the book an aesthetic as well as an intellectual pleasure.

The book is divided into 11 chapters. Chapter 1 introduces the reader to the author's objectives and methods. Some general remarks about the approach of cognitive psychology are provided for nonpsychologists. The general aim is "to describe the human capacity for internalizing the structured sound materials of music by characterizing the nature of internal processes and representations" (p. 6). The more specific aim of Krumhansl's research is "to describe what the listener knows about pitch relationships [mainly in traditional Western music], how this knowledge affects the processing of sounded sequences, and how this system arises from stylistic regularities identifiable in the music" (p. 9). Krumhansl's distinctive way of characterizing internal representations is to depict the similarity relationships within sets of basic elements as distances in a multidimensional space.

The basic elements are said to be single tones, chords, and keys. (That keys are rather more abstract entities than are tones and chords is not immediately pointed out, but perhaps obvious.) Krumhansl does not further defend this axiom, which would be accepted by most music psychologists and musicologists. Witness, however, what Serafime (1988)—not cited in the book—had to say: "On this view, the elements and processes of cognition will be exactly isomorphic to the factors we are able to find ... and manipulate in experiments" (p. 26) and "we know that the stimuli used in such studies are never, under any circumstances, considered or listened to as music" (p. 25). And, further along, Serafime argued that "much psychological research has mistakenly focused exclusively [on], and also misinterpreted, merely the results of reflection—that is, scales, chords, and discrete pitches—rather than been concerned with music itself" (p. 52). I will return to these arguments at the end of this review.
Chapter 2 introduces the reader to the concept of tonal hierarchy, and to Krumhansl’s way of deriving and depicting this cognitive structure. The term “hierarchy” here refers to a simple ordering of tones according to their relative importance or stability within a given key, not to a structure with several nested levels (as in Lerdahl and Jackendoff, 1983). The hierarchy of the tones within a given key is likened to the organization of category members around a prototypical exemplar, in this case the base note or tonic, which serves as a cognitive point of reference. Krumhansl’s experimental probe tone method (developed in collaboration with Roger Shepard) presents listeners with a sequence of notes that unambiguously define a particular key (e.g., a scale or a tonic triad chord), followed by a single note of variable pitch. Subjects judge on a rating scale how well this final probe tone fits into the context of the established key. The resulting pattern of average ratings across all tones of the chromatic scale describes the tonal hierarchy: The tonic (scale step 1) is rated highest, followed in major keys by scale step 5, steps 3 and 4, steps 2 and 7, and finally the chromatic tones that are not members of the key. In minor keys, the order is 1, 3, 5, then steps 2, 4, and 7, and finally the chromatic tones. These hierarchies correspond to the functional importance of the scale notes in traditional tonal music, as described by musicologists.

By computing the auto- and cross-correlations between the rating profiles for all possible pairs of major and minor keys, Krumhansl derives a matrix of interkey similarities that she then subjects to nonmetric multidimensional scaling to obtain a spatial configuration of interkey distances. The configuration is strikingly regular, due to the constraints built into the data, and it also makes sense: Two dimensions in which the points representing the keys are arranged according to the circle of fifths are convolved with two dimensions in which the keys are arranged in a circle that reflects relative and parallel relationships between major and minor keys. The total four-dimensional pattern can be visualized as the surface of a torus (a doughnut), or the surface can be spread out in two dimensions representing the angular coordinates of the keys in the two circular configurations. This latter, two-dimensional key map resembles maps drawn intuitively by musicologists: The key of C major, for example, is adjacent to the major keys differing in one note (G and F major), to the relative minor key (a minor), and to the parallel minor key (c minor). Thus it provides an empirical validation of musicologists’ insights through listeners’ probe tone ratings. Krumhansl adds a cautionary note by pointing out that her model does not account for possible directional asymmetries in key similarity.

Following this methodological tour de force, the author turns in Chapter 3 to a discussion of the factors that may underlie listeners’ knowledge of tonal hierarchies. She considers two: the phenomenon of tonal consonance, and the statistical distribution of pitches in tonal music. Strong correlations of tonal hierarchies with consonance hierarchies would suggest that tonal hierarchies originate in the acoustics of complex tones and therefore are relatively fixed and universal. Stronger correlations with the distribution of tones in familiar music, on the other hand, would suggest that tonal hierarchies are learned and culture-bound. Krumhansl briefly reviews acoustically-based theories of tonal consonance and then proceeds to describe the correlations between her tonal hierarchies and consonance hierarchies culled from various studies in the literature. The correlations are moderately high for major keys but lower and mostly nonsignificant for minor keys. Krumhansl then proceeds to compare the tonal hierarchies with the statistical frequency distributions of tones in various selections of tonal music, again obtained from the literature. These correlations are much higher and significant for both major and minor keys. Finally, a multiple regression analysis is performed which demonstrates that tonal consonance does not account for any aspect of tonal hierarchies that is not also accounted for by tonal frequency distributions. On the basis of these results, Krumhansl argues that tonal hierarchies are learned through listening to tonal music and hence are a product of musical acculturation. Research by Lynch et al. (1990a, 1990b)—too recent to be cited by Krumhansl—indeed suggests that this acculturation begins in the first year of life.

In Chapter 4, Krumhansl turns to a practical application of her tonal hierarchy results: determination of the key for a musical excerpt, and of changes in key as music progresses. Her key-finding algorithm (developed with Mark Schmuckler) is simple: The total duration of each note in the musical excerpt is determined by combining repeated occurrences of the same note, regardless of octave or ordinal position. The resulting relative durations of the 12 notes in the octave (with zero for notes that do not occur) are then correlated with the tonal hierarchy profiles for the 24 major and minor keys, as described in
Chapter 2. The largest correlation identifies the dominant key. Other large correlations identify related keys that may also be suggested by the musical passage. Indeed, the major virtue of the algorithm is seen in its ability to yield a key hierarchy, rather than just a single dominant key. As Krumhansl demonstrates, music theory experts can rate the relative strengths of candidate keys for short musical excerpts.

The effectiveness of the key-finding algorithm is demonstrated in three specific applications and is compared to other procedures proposed in the literature. In the first application, the algorithm is used to determine the nominal keys of preludes (24 each) by Bach, Shostakovich, and Chopin, based on the first four notes only. The results are quite accurate for Bach and Shostakovich, but less so for Chopin. In the second application, 24 fugue subjects of Bach and Shostakovich are analyzed in terms of how many notes are needed to determine the correct key. The average number of notes is about 5, considerably less than required by alternative algorithms proposed in the literature. In the third and most elegant application, the key modulations in a single Bach prelude are tracked measure by measure and compared to judgments by two experts. There is good agreement, though the algorithm does not quite match the experts. The key changes are represented graphically as a path on the surface of the torus representing the configuration of interkey distances (Chapter 2). A final section of Chapter 4 acknowledges the current limitations of the algorithm, which include its insensitivity to temporal order, melodic patterns, harmonic structure, and rhythmic stress.

In Chapter 5, Krumhansl returns to perceptual data and in fact reports an original study not published elsewhere, which replicates and extends one of her early experiments. The topic is the perceived relation between two musical tones. Whereas in the experiments that led to the tonal hierarchy profiles the subjects' task was to judge how well a single note fit into the tonal context established by a precursor sequence, listeners now hear two notes following the key-defining context, and the task is to rate how well the second note goes with the first. The goal is to demonstrate that these perceived relations depend on the tonal context—for example, that the notes C-G are perceived as a better sequence than the notes C#-G# when the key is C major, even though both note sequences represent the same musical interval (a fifth). Krumhansl starts out by discussing various spatial representations of the psychological pitch relations among tones, which increasingly take the functional roles of tones into account. Although the author persists in talking about the perceived relations among successive tones, what her experiment is really about is the functional role of two-note sequences within a given key. It comes as no surprise, then, that the order of the two notes plays an important role, a factor that cannot be accommodated by traditional multidimensional scaling of similarity data. Krumhansl nevertheless presents the results of such an analysis, but also notes its shortcomings. The spatial solution that best approximates the perceived tonal relations shows the tonic at the vertex of a cone, along whose circumference the other tones are arranged according to pitch, but with their distance from the tonic being an inverse function of their position in the tonal hierarchy. A more complete picture including order effects emerges from a multiple-regression analysis: Listeners' judgments were most strongly influenced by the position in the tonal hierarchy of the second tone, with weaker but significant contributions of the tonal hierarchy of the first tone, the pitch distance between the two notes, and the distance between the two notes along the circle of fifths. The chapter concludes with a demonstration that the results are positively correlated with the relative frequencies of melodic intervals in several musical corpora, as tabulated previously by others.

Chapter 6 first summarizes three principles that have emerged from this research and from the work of others on perceptual organization and memory. The principle of contextual identity states that stable tones (i.e., tones high in the tonal hierarchy) are remembered better than unstable tones. The principle of contextual distance states that two tones are perceived as the more closely related (and hence are also more easily confused in memory) the more stable either of them is. The principle of contextual asymmetry states that two tones are perceived as more closely related when the second tone is more stable than the first than when they are in the opposite order. These principles are expressed formally in terms of perceptual distances, and relevant findings are cited from the literature. The principles are said to support basic tenets of Gestalt theory, with tonality providing a kind of Gestalt quality, though (to this reader) this argument does not add any explanatory power. The second half of the chapter discusses perceptual grouping principles in music, with data from several recent studies by the author and her collaborators. These studies show that pitch and rhythm make independent
contributions to perceived phrase structure, that there are reliable boundary cues in performances of pieces by Mozart as well as Stockhausen, and, most intriguingly, that 6-month old infants prefer music that is interrupted at phrase boundaries to music that is interrupted in the middle of a phrase. Lowering of pitch and increases in tonal duration are identified as boundary cues likely to have been salient to these infants, and the analogy to speech prosody is noted.

Chapters 7 and 8 are easily summarized. They report the results of experiments with chords that replicate in all essentials the experiments with tones described in Chapters 2 and 3. Chapter 7 reports data not published previously. Listeners were presented with one (Chapter 7) or two (Chapter 8) triadic chords following a key-establishing context and judged how well they followed the preceding context. The results are shown to reflect the relative stability of the chords in the tonal system, and they illustrate each of the three general principles discussed in Chapter 6. Memory for chords in a sequence is also shown to reflect relative stability, and chord stability is found to correlate with frequency of occurrence of chords in tonal music. Krumhansl concludes by summarizing the many parallels between the perceptual organization of tones and chords.

All the work up to this point can be considered as concerned with establishing basic facts concerning tonal organization in perception and memory. In Chapter 9, Krumhansl summarizes two studies that make use of these basic data in addressing two more complex scenarios: key modulation and polytonality. In the key modulation experiment, probe chords are presented after every single chord of chord sequences that modulate to close or distant keys. By correlating subjects' judgments with the tonal hierarchy profiles obtained previously in unambiguous key contexts (Chapter 2), the relative strengths of different keys can be assessed as the chord sequence unfolds. By treating these strengths as distances, the changing sense of key through the chord sequence can be represented as a path in the toroidal key-distance map derived in earlier studies. The analysis reveals listeners' initial resistance to radical key changes, followed by abrupt shifts into the new key when the following context confirms it. In the experiment on the perception of polytonality, a famous excerpt from Stravinsky's "Petrouchka" is used in which two distant keys (C# and F# major) are used simultaneously. Probe tones are presented after the bitonal passage, as well as after each tonal component played separately. Detailed analysis of the results suggests that subjects' judgments are governed by the notes presented, and hence also by both keys, but that no clear sense of either tonality develops. Listeners were generally unable to focus on one or the other tonality, even when instructed to do so. Thus it seems that polytonality, in this instance at least, prevents the establishment of either a single or a multiple tonal framework; instead, it creates ambiguity.

The author ventures farther afield in Chapter 10, which reports studies that applied the probe tone technique to 12-tone serial music, to North Indian classical music, and to Balinese gamelan music (the last study done by Kessler and colleagues). The resulting probe tone profiles, obtained at various points during and/or following musical excerpts from these various styles, were analyzed to determine the factors that played a role in subjects' judgments. In the study of 12-tone music (excerpts from two of Schoenberg's works), two groups of subjects could be distinguished whose patterns of responding were almost exact opposites of each other: One group, generally more familiar with 12-tone music, avoided tonal implications like the plague, whereas the other group was governed by whatever tonal implications they could derive from surface features such as note length and recency. Similarly, in the experiment using North Indian music in different keys (thats), experienced subjects gave probe tone profiles that enabled Krumhansl to recover through multidimensional scaling analysis the key (that) distance map postulated a priori, whereas other subjects gave a much less clear pattern and seemed to be governed by surface features of the music rather than by the underlying scales. Krumhansl's conclusion that "listeners can set aside ... expectations and hear the pitch events in style-appropriate terms quite independently of their prior musical experience" (p. 268) is perhaps premature, but her results demonstrate that musical compositions in different styles often provide the "surface" information (emphasis, repetition, lengthening of important notes) a listener needs to infer the characteristics of the style, so the prior experience is simply not needed to appreciate simple structural features. Interestingly, orthodox 12-tone music is different in that it studiously avoids such surface aids to the listener, so, in order to respond appropriately to this music, listeners need to know what not to expect. This is an interesting demonstration of the inherent radicalism of dodecaphonic music, and an indication that it negates not only traditional (i.e., 19th century) aesthetic values but psychological principles as well.
In her final chapter, Krumhansl first discusses rather briefly some formal properties of the tonal system and of some other scale systems, and speculates that these properties may have arisen from psychological constraints, thereby suggesting interesting future research to be done. The final pages summarize the principal findings from the empirical studies. The perception of tonal music is said to exhibit "one of the hallmarks of a cognitive system: the categorization and classification of sensory information in terms of a stable, internal system of structural relations" (p. 282). That system, Krumhansl claims, is abstracted and internalized by listeners from the sound events in the music they encounter; that is, it is learned and style-specific, though it makes use of general cognitive architecture to represent the external regularities.

Krumhansl's book is a superb accomplishment and represents cognitive psychology at its best. This does not mean that it is beyond criticism. The question is, quite simply, whether cognitive psychology at its (current) best is good enough to explain musical phenomena. Music is a very highly developed art form whose complexities have kept musicologists busy for centuries. Cognitive psychology is not particularly well suited to studying art forms, or at least has not yet proven to be. What, to Krumhansl, are major insights gained from a decade of research may be platitudes to a musicologist (Butler, 1990) or musician. This problem is endemic to cognitive psychology, which searches for general principles that cut across many domains. However, it is with the specific properties of music that the study of music proper begins. It could be argued that cognitive psychology and the serious study of music are mutually exclusive, though perhaps complementary. If so, then even a tour de force such as Krumhansl's research will inevitably miss the significant issues in music perception. Nevertheless, it may provide a general framework within which these music-specific issues may be addressed in a more rigorous manner.

The probe-tone task has been criticized by Butler (1989) as being insensitive to the dynamic unfolding of harmonic implications in tonal music, as permitting alternative listener strategies, and as being more sensitive to the tone distributions in the key-defining context than to the implied tonality. Krumhansl's reliance on tabulations of note durations and frequencies was likewise attacked by Butler as being a crude method. The resulting exchange (Krumhansl, 1990; Butler, 1990) has not settled these issues completely, and further research will be necessary. It certainly would be inappropriate to conclude (as Butler tends to do) that any of Krumhansl's results are artifactual until they have been proven to be so by careful follow-up experiments. For one thing, most of her findings are in good agreement with conventional musical wisdom, which makes it likely that they will stand the test of time. It seems to this reviewer that Krumhansl has justifiably ignored some significant musical detail in order to arrive at generalities, but the detail will have to be dealt with eventually. The dynamic tracing of harmonic expectations described in Chapter 9 certainly is an interesting beginning in that direction. Unfortunately, the probe tone method becomes prohibitively time-consuming as a tool for investigating modulations in real music, and trained musicologists' judgments may ultimately prove not only more convenient but also more reliable.

Like most cognitive psychology studies, Krumhansl's research is not concerned specifically with expert knowledge. After finding early on that musically untrained subjects tend to use nonmusical response strategies in the probe tone task, she relied in the following on listeners who had considerable musical training but were not necessarily professional musicians or musicians. This is both a strength and a weakness. It is a strength in so far as it demonstrates the solid, ingrained knowledge musically informed listeners have of the tonal system. It is a weakness in that it does not characterize what, if anything, musically uninformed listeners know about music, and, more importantly, that it misses the special skills and insights provided by highly trained musicians and musicologists. In any investigation of a highly developed art, expert judgments must be the measure of validity—even if those judgments sometimes diverge. The consensus of average listeners can tell us what the average listener knows, but it will not capture the full subtlety of the phenomena under investigation.

What about Serafine's (1988) warnings, cited at the beginning of this review? It is certainly true that Krumhansl took certain musical elements—the "results of reflection"—as given and proceeded to develop her representations of mental structures in terms of those units (tones, chords, and keys). Her claim is undoubtedly that, even when not reflected upon, these units play a functional role in mental processing. It is also true, however, that the probe tone task directs the listener's attention to a particular unit (a tone or chord) and requests a judgment about it in the context of an
often stereotyped and much-repeated, musically trivial context that, moreover, is rendered in electronic sound and with mechanical timing and dynamics. There are exceptions, such as the experiment using actual excerpts from Schoenberg's music as the context for probe tones (Chapter 10). On the whole, however, it is quite possible that the musical samples in Krumhansl's experiments were not "listened to as music," by which Serafine (1988) presumably means that they were not perceived as musically meaningful or expressive. It is the more remarkable, then, that these meaningless sequences inevitably and strongly engaged the listeners' knowledge of tonal hierarchy structures; in a sense, then, they had some musical meaning, after all. It is the cognitive psychologist's trump card that even highly schematic stimuli often engage mental structures designed for much more complex and ecologically valid events. It is the expert's wild card, however, that only a very limited subset of pertinent structures can be probed in this way, so that an impoverished view of complex phenomena may result.

In her introduction, Krumhansl refers several times to "musical experience," but her research does not really deal with listeners' experiences. They made judgments that followed certain patterns; what they experienced, we do not know—probably boredom. Krumhansl's spatial maps present us with crystallized configurations—mental structures in vitro, as it were, that can be regarded with awe, like a piece of modern architecture. They convey none of the excitement and pleasure that comes from exploring the building, its corners and hallways. For an appreciation of musical meaning, we must read Langer (1953) or Zuckerkandl (1956) or Clynes & Nettheim, (1982)—or simply listen. Krumhansl's cognitive world is one of discourse about music, not of music as "significant form" (Langer, 1953). Yet, there must be a close relation between the two. The characterization of that relation is perhaps the fundamental problem of music psychology. Krumhansl would be well equipped to tackle it as the next step in her remarkable career.

REFERENCES


References


FOOTNOTES


1That is, considered as a post-war empirical enterprise. The psychology and philosophy of music have, of course, a distinguished history that goes back many centuries.

2Interestingly, the map goes beyond earlier representations in that it suggests that C major is closely related to yet another key, e minor—which, in its descending melodic version, differs in just one note from C major—but not to d minor, which also differs in one note. It is not clear whether this observation is substantiated by any musicological evidence.

3A consonance hierarchy—my term—results from quantitative estimates of predicted or perceived consonance for all tones of a scale when they are sounded together with the tonic of that scale.

4It is possible to regard the two-tone judgment task as a version of the one-tone task: The first probe tone merely extends or perturbs the tonal context in which the second tone is judged.

5An unfortunate mistake in this otherwise very carefully edited volume occurs in the musical examples on page 229: The bottom staves should be in treble clef throughout, not in bass clef. On the same page, in the penultimate line, "diminished triads" should read "diminished chords." Also, Krumhansl's spelling of "Petrouchka" is an unfortunate amalgam of Stravinsky's original French "Pétrouchka" and its anglicized version, "Petrushka".

6An error occurs on page 277: There are not two but three octatonic scales; the "2-scale" was mistakenly omitted from Table 114.4 at the bottom of the page.

7One of the arguments revolves around the fact that the original tonal hierarchy profiles were based on data from a subset of contextual conditions in which the most stable tones occurred more often than the unstable tones. It appears that Krumhansl and Kessler selected those conditions that were most effective in inducing a sense of key, and it is not surprising that these contexts were precisely those that emphasized stable tones. Butler's question of whether the subjects' ratings reflected their sense of key or the frequency of occurrence of the stable tones seems somewhat academic.