# SYSTEMATISCHE MUSIKWISSENSCHAFT

SYSTEMATIC MUSICOLOGY
MUSICOLOGIE SYSTÉMATIQUE

III/2 – 1995

## EXPERIMENTELLE UND EMPIRISCHE MUSIKFORSCHUNG

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## EXPERIMENTAL AND EMPIRICAL MUSIC RESEARCH

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## Introduction

Empirical and experimental methodology has become an integral part of musicological research. Research directed to the investigation and explanation of basic problems in music, concerning its acoustical and psychophysical foundations as well as actual sound, was closely related to experimental procedures From the Hellenic period to the Renaissance, and from new developments in science and acoustics in the 17th and 18th centuries to the rise of modern musicology in the 19th as well as the 20th century (with Hermann von Helmholtz, Carl Stumpf and many others who followed their ideas), have provoked very many scientists, schools of research, institutions and projects, to apply experimental procedures in their work.

Intonation practice as related to tone-systems, musical structure and actual performance, cognitive processes underlying musical composition, music making as well as music perception, identification of musical instruments and their sound, sound analysis and synthesis, are only some of the many issues in a wide scope of problems covered by experimental music research.

The articles that are joined in this volume in particular cover the following fields of research: musical context, similarity and expectancy, the masking effect, musical performance, the cognitive process concerning music, the sound spectra in speech, music, and violin strings, the vocal drone, the register structure of vocal sound in the Beijing opera, reception and aesthetic evaluation in the opera.

At the symposium held at Schloß Zeillern (Austria) in 1995, prepared by the Institute of Musicology of the University of Vienna in cooperation with the International Cooperative in Systematic and Comparative Musicology, an amazing number of projects and studies were presented, a selection of which has been edited to be published in this volume of Systematic Musicology.

We like to thank all authors who have sent in their studies to be processed for publishing in this volume. Special thanks are due to some young colleagues who took the opportunity to present (preliminary as well as full-grown) results of their experimental and other empirical music research in this issue.

Oskár Elschek



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# Effects of Musical Context on Similarity and Expectancy

**Summary**

Musical context has remarkably strong effects on similarity relations and expectancies in music perception. This article reviews effects of tonality on the perceived similarity of tones and chords. Three principles emerge that can be accounted for by the tonal and harmonic hierarchies established by the tonality of the context. This article then presents two music theoretical proposals that make predictions for effects of musical context on expectancies, the intervallic-rivalry model (Brown, Butler, & Jones,1994) and the implication-realization model (Narmour,1990). To test these theoretical proposals, an experiment was conducted to investigate the tonal and melodic implications of a comprehensive sampling of musical intervals. Twenty-three context intervals (ranging from a descending to an ascending major seventh) are each followed by twenty-five continuation tones (spanning a two-octave range). Listeners judge how well the continuation tones fit with their expectancies. The results are modeled as the joint influence of three factors: tonality, consonance, and principles of perceptual organization. Limited support is found for the two music theoretical proposals, suggesting the claims of these models can be justified only partially on psychological grounds.

**Zusammenfassung**

Der musikalische Kontext übt einen bemerkenswert starken Einfluß auf die Wahrnehmung von Ähnlichkeitsbeziehungen und Erwartungen mit Bezug auf Musik aus. Der vorliegende Beitrag untersucht den Einfluß der Tonalität auf die wahrgenommene Ähnlichkeit von Tönen und Akkorden. Es treten drei Prinzipien in Erscheinung, die sich durch tonale und harmonische Hierarchien erklären lassen; diese ergeben sich wiederum aus dem tonalen Kontext. Sodann erörtert der Beitrag zwei musiktheoretische Ansätze, die Hypothesen zum Einfluß des musikalischen Kontextes auf die Hörerwartung beinhalten, und zwar (a) das sog. intervallic-rivalry model (Brown, Butler & Jones 1994) und (b) das implication-realization-Modell von Narmour (1990). Um diese theoretischen Ansätze zu testen, wurde ein Experiment durchgeführt, mit dem die tonalen und melodischen Implikationen einer größeren Anzahl musikalischer Intervalle untersucht wurden. Dreiundzwanzig Intervalle im Kontext, die von einer absteigenden bis zu einer aufsteigenden großen Septime reichen, werden jeweils mit 25 Tönen fortgesetzt, die insgesamt zwei Oktaven umfassen. Hörer beurteilten, wie gut diese Fortsetzungstöne mit ihren Erwartungen übereinstimmten. Die Ergebnisse lassen sich als gemeinsamer Einfluß dreier Faktoren darstellen: Tonalität, Konsonanz, und Prinzipien der Wahrnehmung. Für die beiden musiktheoretischen Ansätze ergaben sich empirisch nur teilweise Befunde, die zur Unterstützung dieser Modelle durch psychologische Fakten geeignet sind.

**Sommaire**

Le contexte musical a des effets significatifs sur les relations de similarité et l'expectative dans la perception de la musique. Cet article passe en revue les effets de la tonalité sur la perception de la similarité des sons et des accords. Surgissent trois principes pouvant expliquer les hiérarchies tonales et harmoniques établies par la tonalité du contexte. Cet article présente deux propositions musicales théoriques relatives à la prévision des effets du contexte musical sur l'expectative, le modèle intervalles-rivalité (intervallic-rivalry model de Brown, Butler & Jones 1994) et le modèle de réalisation et de l'implication (implication-realization model de Narmour 1990). Pour tester ces propositions théoriques, une expérience a été menée afin de rechercher les implications tonales et mélodiques d'un échantillonnage d'ensemble d'intervalles musicaux. Vingt-trois intervalles contextuels (allant d'un septième majeur descendant à un septième majeur ascendant) sont suivis chacun de vingt-cinq sons de prolongement (englobant une étendue de deux octaves). Les auditeurs jugent si les sons de prolongement répondent à leur expectative. Les résultats sont modélisés en tant qu'influence conjointe de trois facteurs: la tonalité, la consonnance, et les principes d'une organisation perceptuelle. Un support limité est déterminé pour ces deux propositions musicales théoriques, suggérant que les prétentions de ces modèles peuvent seulement être partiellement justifiées sur des bases psychologiques.

**Keywords:** musical context, similarity, music perception, tones, chords, tonality, musical intervals, consonance, harmonic hierarchies

Music is a strategic realm in which to study certain basic psychological questions. One question that emerges in studying many different domains of behavior is the effect of context. Context, as we know, influences how we perceive objects in visual scenes, interpret linguistic utterances, what we remember from experienced events, and how we interpret the motivations underlying the actions of others. Context in music strongly determines how we perceive individual tones and chords. Isolated tones and chords have no intrinsic referential meaning. Reflecting on this Wertheimer says, "The flesh and blood of a tone depends from the start upon its role in the melody: A B as leading tone to C is something radically different from the B as tonic." (Wertheimer,1938, p. 5) Given the freedom that musical elements have from fixed referential meanings, studying context in this domain has the promise of uncovering basic psychological principles. The study is further aided by music theoretical concepts, especially tonality, that usefully characterize properties of musical contexts. This article will focus on two important effects of context on the perception of tones and chords: contextual effects on similarity, and contextual effects on expectancy for subsequent events.

## Context and similarity

Tonality, or key, is a music theoretical concept that is central to understanding how context affects the psychological similarity of tones and chords. The discussion here will use tonality as it applies to traditional tonal-harmonic music. More general definitions of tonality have been developed for a wider range of styles. Tonality, in theoretical treatments, specifies the scale and mode of the music. It also imposes hierarchies on the tones and chords. The hierarchies will be described as an ordering in terms of stability. For tones, theoretical treatments describe the first scale degree (the tonic) as the most stable tone, followed by the fifth scale degree (the dominant), followed by the third scale degree (the mediant), and so on. For chords, the most stable chords are considered to be the chord built on the first scale degree (I, tonic triad), the chord built on the fifth scale degree (V, dominant), and the chord built on the fourth scale degree (IV, subdominant). Stability has a variety of compositional correlates. For example, tones and chords that are stable appear relatively more frequently, especially in strong metrical positions and at the beginnings and ending of phrases.



Stability also has a variety of perceptual correlates that can be measured experimentally. One method, called the probe tone method (Krumhansl & Shepard,1979; Krumhansl & Kessler, 1982; Krumhansl,1990 a), asks listeners to judge how well each tone of the chromatic scale completes or fits with a key-defining context. The key-defining contexts used in the experiments include incomplete and complete scales, chords, and chord cadences. In this method, listeners make their rating on a numerical scale. Representative results are shown at the top of Figure 1 for the key of C major. Other experimental measures show the same pattern, such as the probability of recognizing a tone that is repeated after some delay, the accuracy of naming by musicians with absolute pitch, the latency with which tones are judged to be members of the scale, and the judged acceptability of tones at the end of phrases. Analogous results have been obtained for chords. For example, the top of Figure 2 shows results from a probe chord procedure (Krumhansl,1990 a) in which single chords were presented following a key-defining context.

These effects have been formalized (Bharucha & Krumhansl,1983; Krumhansl,1990 a) by a principle called Contextual Identity. The principle says that more stable elements (tones or chords) have stronger identities. This can be recast in terms of psychological distance. If a tone or chord, a, is relatively unstable two instances of it may not be perceived as identical. In other words, the psychological distance between the two instances, d(a,a), may be greater than zero. Conversely, two instances of a stable tone or chord would be perceived as more nearly identical. Thus, the principle can be written:

**Contextual Identity:** d(a,a) decreases as the stability of the element (tone or chord) in the tonality increases.

This notion of a hierarchy of stability can then be used to understand how musical context affects similarity. The effects for tones are described by Cuddy, Cohen, and Miller (1979), Krumhansl (1979), and Krumhansl (1990 a); the effects for chords are described by Bharucha and Krumhansl (1983) and Krumhansl, Bharucha, and Castellano (1982). In these studies, some of the experiments presented key-defining contexts followed by two tones or two chords. Listeners were asked to judge the similarity of the first element to the second element in that context. The results showed strong effects of context. Two tones, or chords, that occupy relatively high positions in the hierarchies were judged as relatively similar, whereas tones or chords that occupy relatively low positions were judged as dissimilar. Multidimensional scaling of

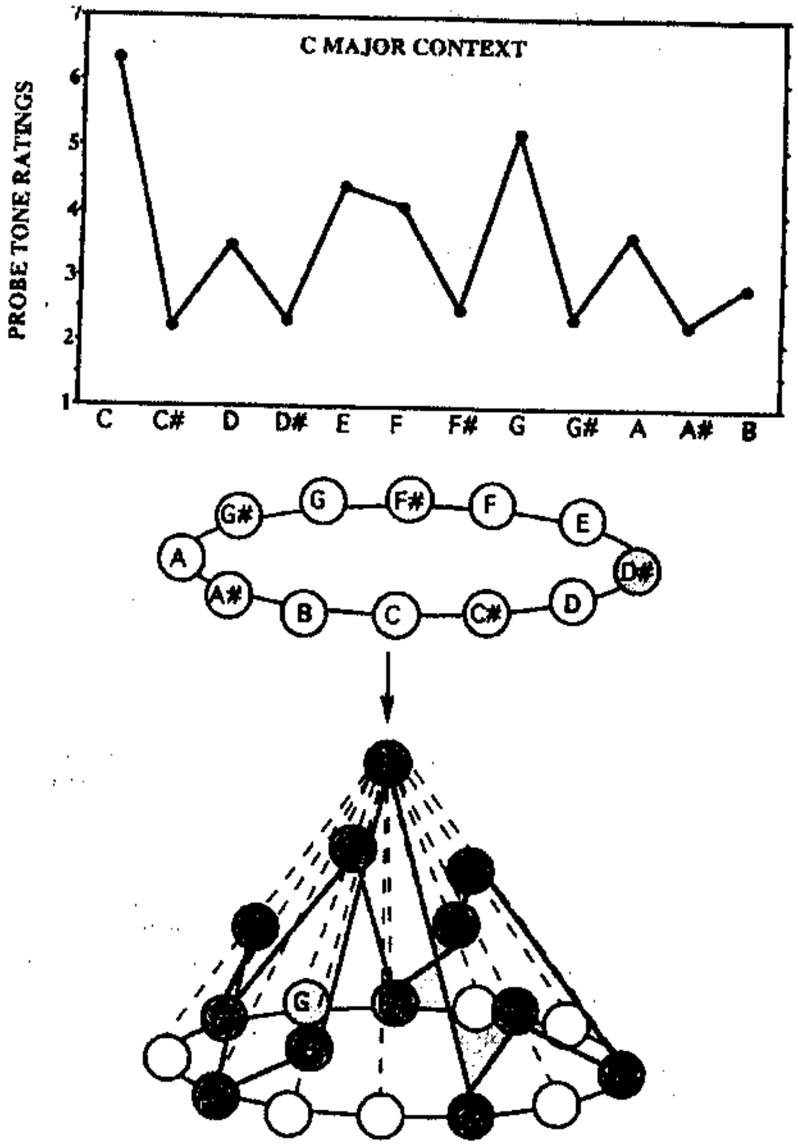



*Figure 1: The top of the figure shows the probe tone ratings from Krumhansl and Kessler (1982); this pattern of results is called the tonal hierarchy. The center of the figure shows the chroma circle representation of tones. The bottom of the figure shows how this representations is altered by a C major context.*



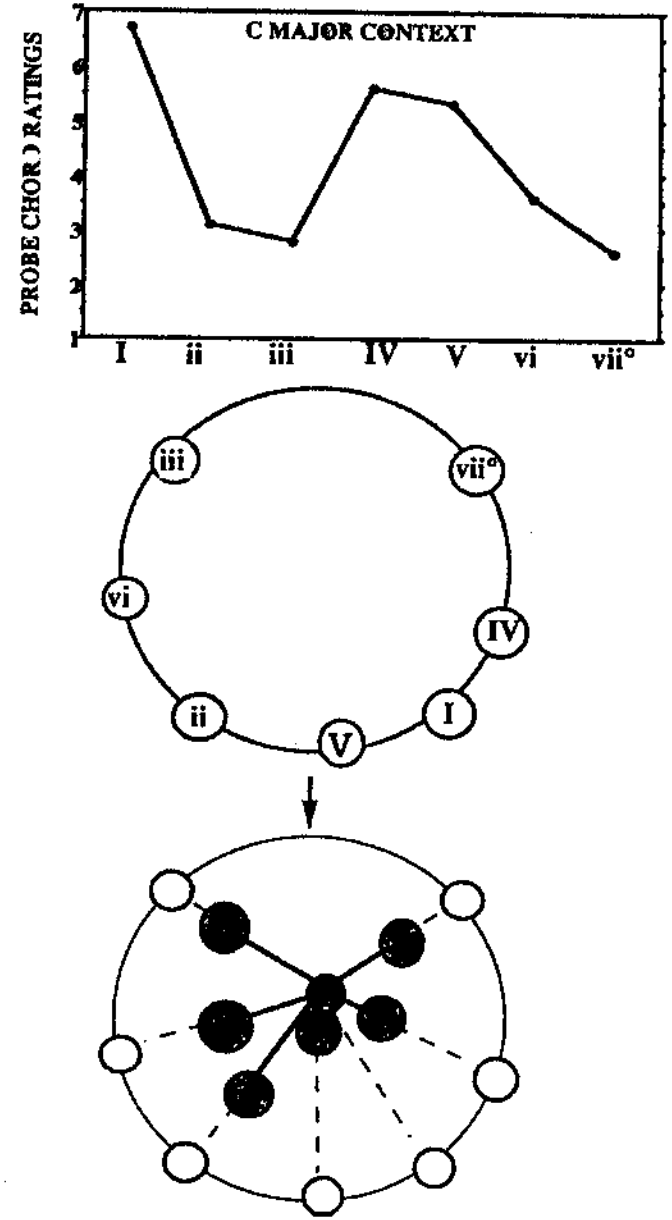



*Figure 2: The top of the figures shows the probe chord ratings from Krumhansl (1990 a); this pattern of results is called the harmonic hierarchy. The center of the figure shows the circle of fifths for chords. The bottom of the figure shows how this representation is altered by a tonal context.*

these judgments produced the kinds of solutions shown at the bottom of Figures 1 and 2. Other experiments in these studies used memory confusions as a measure of similarity. These experiments find greater confusions between tones or between chords that occupy relatively stable positions in the hierarchies, as would be expected given the similarity results.

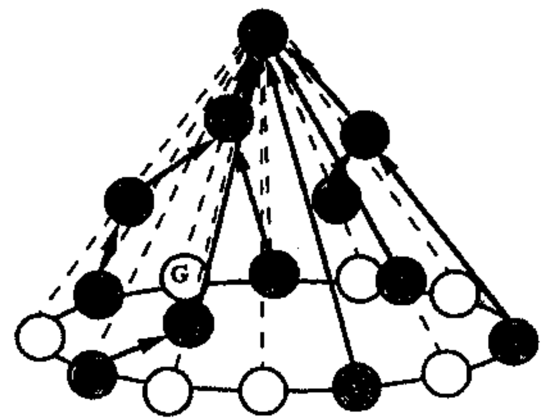
To show these effects graphically, one representation of the similarity between tones is the "chroma circle" shown at the center of Figure 1 (Shepard, 1964). This representation collapses tones across octaves, and neighboring tones on the circle are proximal in pitch. In a musical context, the relations are altered by the tonal hierarchy as shown at the bottom of the figure. Similarly, one possible representation of the similarity between chords is the "circle of fifths for chords" shown at the center of Figure 2. In a musical context, the relations are altered by the harmonic hierarchy as shown at the bottom of the figure. These alterations can be described by a second principle called Contextual Distance. This says that the psychological distance between tones or between chords decreases with the stability of the elements. This principle is formalized as:

**Contextual Distance:** d(a,b) and d(b,a) decrease with the stability of the elements a and b.

The third and final principle specifies how musical context induces temporal order effects. In a similarity judgment task, the rating of the pair of elements (a,b) is not necessarily the same as the rating of the pair of elements (b,a). The temporal order effects found for tones (Krumhansl, 1979; Krumhansl,1990 a) and chords (Bharucha & Krumhansl,1983; Krumhansl, Bharucha, & Castellano,1982) depend on the elements' positions in the hierarchy of stability. Similarity is greater when the more stable element occurs second. Memory measures also show temporal order effects. If the to-be-remembered tone is a and the test tone is b, the probability of confusion may be different that if the to-be-remembered element is b and the test element is a. Parallel to the effect of similarity, there is a greater probability of confusing the less stable element with the more stable element than the reverse.

These effects cannot be represented simply in a multidimensional scaling solution because distances in the spatial representation are symmetric, that is, d(a,b) = d(b,a). However, Figure 3 shows graphically some of the temporal order effects found for tones in the context of C major (based on the data of Krumhansl,1990 a, p.125). An arrow is drawn between each tone and the tone to which it is judged most similar. For example, G# is judged most similar to A, which is judged most similar to G, which is judged most similar to C. The bottom of the figure shows these similarity values on the left. For comparison, the similarity values for the reverse temporal order are shown on the right. The temporal order differences, as can be seen, are relatively large. Similar temporal order effects are also found for chords, as shown graphically in Figure 4 (based on the data of Bharucha & Krumhansl,1983; shown in Krumhansl,1990 a, p.193). These temporal order effects can be summarized by a third principle, Contextual Asymmetry, which is formalized:






C MAJOR CONTEXT

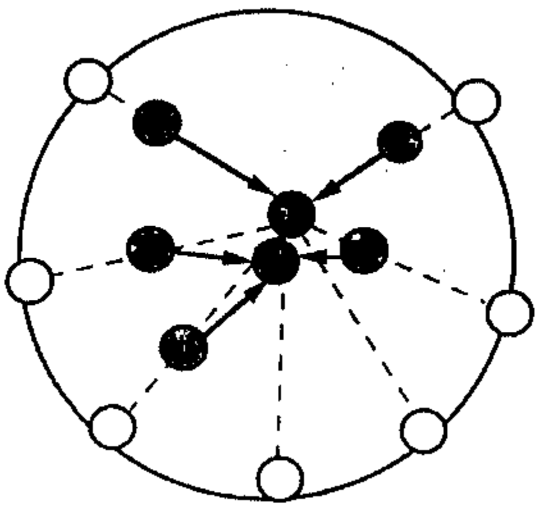
SIMILARITY JUDGMENTS

| TOWARD NEAREST NEIGHBOR | | AWAY FROM NEAREST NEIGHBOR | |
|---|---|---|---|
| C# C | 3.8 | C C# | 2.3 |
| D C | 6.2 | C D | 5.8 |
| D# E | 3.6 | E D# | 3.0 |
| E C | 6.3 | C E | 5.0 |
| F E | 5.3 | E F | 4.5 |
| F# G | 5.1 | G F# | 3.0 |
| G C | 6.9 | C G | 5.8 |
| G# A | 3.1 | A G# | 2.8 |
| A G | 5.4 | G A | 5.0 |
| A# | 3.3 | B A# | 2.2 |
| B C | 6.4 | C B | 3.7 |

*Figure 3: The top of the figure shows graphically the nearest neighbor relationships for tones. The bottom of the figure gives the similarity ratings of each tone to its nearest neighbor (left) and the similarity rating of the reverse temporal order (right). The data are from Krumhansl (1990 a).*

**Contextual Asymmetry:** d(a,b) > d(b,a) when a is more stable than b.

To summarize, these three general principles characterize how a musical context influences psychological relations between tones and between chords. Tonality plays a central role in this account. Tonality imposes hierarchies of stability on tones and chords, as described by both theoretical treatments and empirical results. This hierarchy produces a variety of perceptual and cognitive effects which appear in direct similarity judgments,



C MAJOR CONTEXT

SIMILARITY JUDGMENTS

| TOWARD NEAREST NEIGHBOR | |
|---|---|
| ii V | 6.1 |
| iii I | 5.4 |
| IV V | 6.0 |
| V I | 6.2 |
| vi V | 5.6 |
| vii° I | 5.9 |

| AWAY FROM NEAREST NEIGHBOR | |
|---|---|
| V ii | 4.8 |
| I iii | 4.8 |
| V IV | 5.5 |
| I V | 5.9 |
| V vi | 5.2 |
| vii° I | 4.6 |

*Figure 4: The top of the figure shows graphically the nearest neighbor relationships for chords. The bottom of the figure gives the similarity ratings of each chord to its nearest neighbor (left) and the similarity rating of the reverse temporal order (right). The data are from Bharucha and Krumhansl (1983).*

memory confusions, and a number of other psychological measures. The context strengthens the relationships between the relatively stable elements (tones or chords). It also introduces temporal order asymmetries in the psychological relations. Less stable elements are more psychologically related to more stable elements than the reverse. These results for pairs of elements are relatively simple to describe and find quite consistent empirical support. Less is currently know about the effect of musical context on expectancies, to which we now turn.



**Context and expectancy: Principles of perceptual organization**

Expectancy plays a central role in Meyer's (1956) account of musical meaning and the emotional response to music. He proposed that expectancy generates musical meaning and the emotional response to music. Patterns in music are recognized as similar to patterns in music listeners have heard previously. Knowledge of the musical style, with its conventional use of certain melodic, harmonic, and rhythmic elements, allows listeners to develop expectancies during listening. Previous hearings of the particular piece may also generate expectancies but, according to Meyer (1967), these do not completely override influences of style knowledge. Expectancies, it is hypothesized, may also come from general principles of perceptual organization, such as those proposed by the Gestalt psychologists. Principles analogous to proximity, similarity, and good continuation in visual perception guide expectations for melodic contour, interval and temporal patterns, and musical form. Whatever their source, expectancies help listeners organize the sounded events for perception, memory, and performance, and the emotional response depends on the match between the music and listeners' expectancies Expectancies may be fulfilled or not, or fulfilled at a delay, creating cycles of tension and resolution.

Narmour (1990) recently proposed an elaboration of Meyer's theory, called the implication-realization model. The model distinguishes between top-down and bottom-up processes in music perception. Top-down processes refer to the ways in which previous musical experience influences how a particular piece of music is encoded, interpreted, and remembered. The top-down component includes knowledge of factors such as harmony and tonality, as well as prior knowledge of the particular piece and the style in which it is written. The bottom-up component of the model consists of general perceptual processes, derived in part from Gestalt principles such as proximity, good continuation, and similarity. They are presumed to apply to all styles of music and independently of the listener's musical expertise and experience.

Implicit in the model are five bottom-up principles that govern listeners' expectancies for melodic continuation These principles are stated precisely in terms of the parameters of interval size and direction. As shown schematically in Figure 5, a melody continues until it reaches a point of instability. Meter, rhythm, and harmony all contribute to creating this instability. The interval that occurs at the point of instability is called the implicative interval because it carries implications for how the melody will continue. The next interval that occurs is called the realized interval. The principles specify, given any paracular implicative interval, classes of tones that are expected to follow.

The first principle is:

**Implication-Realization 1 (Proximity):** The principle of proximity is satisfied if the realized interval is proximate (a perfect fourth, P4, or smaller).

Proximity is considered graded in strength, with a realized interval of a

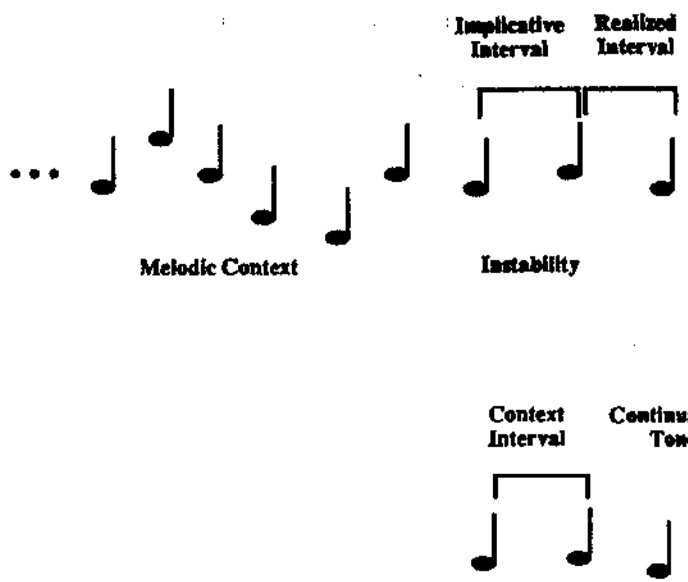



*Figure 5: Shows the correspondence between the design of the present experiment and the implicative and realized intervals of Narmour's (1990) implication-realization model. The model defines an implicative interval to be the interval that appears at a point of instability in a melody; the realized interval is the next interval.*

unison the most proximate and the perfect fourth (P4) the least proximate. All intervals larger than a perfect fourth are nonproximate. This principle is similar in spirit to the Gestalt principle of proximity, but is specialized to musical pitch by specifying the exact boundary between proximate and non-proximate intervals.

The second principle is:

**Implication-Realization 2 (Registral Return):** The principle of registral return is satisfied if the first tone of the implicative interval and the second tone of the realized interval are no farther apart than a major second (M2).

This principle, like the first, can be related to the Gestalt principle of proximity. However, it refers to the interval between first tone of the implicative interval and the second tone of the realized interval, rather than to the second tone of the implicative interval and the second tone of the realized interval (i.e. the realized interval). Notice that the model predicts a considerably narrower range of proximity for the former interval than for the latter (a major second, M2, rather than a perfect fourth, P4).

The third principle is:

**Implication-Realization 3 (Registral Direction):** The principle of registral



direction is satisfied under the following conditions. If the implicative interval is small (a perfect fourth, P4, or smaller), the implicative and realized intervals are in the same direction. If the implicative interval is large (a perfect fifth, P5, or larger), the implicative and realized intervals are in different directions.

Same direction refers to cases in which both implicative and realized intervals are ascending, descending, or lateral (no change in pitch). Different direction refers to cases in which the direction of implicative and realized intervals are different, that is, ascending-descending, ascending-lateral, descending-ascending, descending-lateral, lateral-ascending, and lateral-descending. Small implicative intervals imply that the direction will be the same, an instance of the Gestalt principle of good continuation. Large implicative intervals imply that the direction will reverse, possibly analogous to a principle of symmetry or near-symmetry. In the theory, an implicative interval of a tritone, TT, is ambiguous with respect to the direction of the realized interval, and this ambiguity is resolved by context.

The fourth principle is:

**Implication-Realization 4 (Closure):** The principle of closure is satisfied when a) the direction of the implicative interval and the direction of the realized intervals are different, or b) the implicative interval is larger than the realized interval (by more than a minor third, m3, if implicative and realized intervals are in the same direction, and by more than a major second, M2, if implicative and realized intervals are in different directions).

Note that both conditions can hold simultaneously; in this case, closure is stronger than when only one of the conditions holds. As noted in connection with the third principle, reversal of registral direction (part a) might be seen as related to a principle of symmetry or near-symmetry. It is harder to find an analogous Gestalt principle for large intervals creating expectancies for smaller intervals (part b).

The last principle is:

**Implication-Realization 5 (Intervallic Difference):** The principle of intervallic difference is satisfied under the following conditions. For small implicative intervals (perfect fourth, P4, or smaller), the realized interval is similar in size to the implicative interval (the same size plus or minus a minor third, m3, if implicative and realized intervals are in the same direction; the same size plus or minus a major second, M2, if implicative and realized intervals are in different directions). For large implicative intervals (perfect fifth, P5, or larger), the realized interval is smaller than the implicative interval (smaller by more than a minor third, m3, if the implicative and realized intervals are in the same direction; smaller by more than a major second, M2, if the implicative and realized intervals are in different directions).

This principle of intervallic similarity for small implicative intervals is an example of the Gestalt principle of similarity applied to musical intervals. The principle for large implicative intervals, that a smaller interval is expected, is more difficult to relate to Gestalt principles.

Krumhansl (1991,1995) developed these predictions into a quantitative model that was tested against perceptual data The experiments used excerpts from music in different styles: English folk songs, atonal songs, and Chinese folk songs. These excerpts were followed by continuation tones in a two-octave range centered on the last tone of the excerpt. Listeners judged each of the continuation tones in terms of how well it fit with their expectancies for continuation The study will be described in more detail later, but the results generally supported the five principles proposed by the implication-realization model (Narmour,1990) A follow-up study by Cuddy and Lunney (1995) used the same general method, except that the contexts were two-tone intervals rather than melodic excerpts They were also concerned with possible effects of musical training. However, their musically trained and untrained listeners produced quite similar responses. This study also found support for the predictions of the implication-realization model.

However, both studies used only a limited range of intervals. Moreover, the results of Cuddy and Lunney suggested certain modifications of the model's principles as originally formulated.

To further explore how context affects expectancies, the experiment that will be reported here used an expanded range of two-tone intervals. The context intervals, which are considered equivalent to the implicative intervals in Narmour's (1990) theory (see Figure 5 bottom), ranged from a descending major seventh (M7) to an ascending major seventh (M7). The continuation tones, forming the realized interval, covered a two-octave range The expanded data set from this experiment can be used to address a number of issues that remain from the earlier studies. One issue is that the five principles presented above are not all mutually compatible For example, for most small implicative intervals, a realized interval cannot simultaneously satisfy registral direction and closure. Nor are all the principles independent of one another. For example, the principle of closure overlaps to some degree with the principle of intervallic difference. Finally, experimental results can be used to determine the degree of specificity that can be justified on psychological grounds. The principles were presented here roughly in order of complexity. Proximity, at the one extreme, is a general preference for small realized intervals and is independent of the size of the implicative interval. Intervallic difference, at the other extreme, is very precisely specified in terms of the sizes and relative directions of implicative and realized intervals. The expanded data set will be used to test simpler formulations of the implication-realization model.

The results of the Cuddy and Lunney (1995) experiment also touch on another set of theoretical concerns. Their data indicated that listeners assign rich tonal interpretations to the context intervals. They developed a quantitative predictor variable, called tonal region, that summarizes these tonal interpretations Specifically, tonal region assumes that each context interval



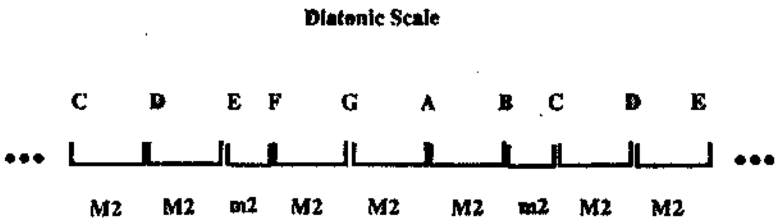
invokes all musical keys that contain the interval in their scale. The tonics of these keys (e.g., the tone C in the key of C major) received higher ratings as continuation tones. In addition, listeners assigned higher ratings to combinations of context intervals and continuation tones that matched the tonal hierarchies found in an earlier experiment (Krumhansl & Kessler,1982), giving rise to a second quantitative variable called tonal strength. The present data will be used to investigate whether their findings generalize to a larger set of musical intervals, and whether a more parsimonious formulation can be found than their tonal region and tonal strength factors.

## Context and expectancy: Tonality and intervallic-rivalry

A music theoretical proposal by Butler and Brown (Butler,1989; Brown, Butler, & Jones, 1994) takes an alternative view of tonal interpretations. Their intervallic-rivalry model claims that intervals that are relatively rare in the diatonic scale are the most potent for establishing a key. The model, described in more detail below, is based on the observation that a major diatonic scale contains only one tritone and only two minor seconds. Other intervals appear more frequendy.

For example, the diatonic scale contains five major seconds, four minor thirds, and so on Another way of stating this is that the rarer intervals appear in fewer scales than other intervals; in fact, the tritone together with any third tone appears in only one scale. Logically it would seem to follow from this that if a relatively rare interval is sounded, it ought to serve as a very reliable cue as to key. In an information-theoretical sense, rare intervals carry more information than other intervals, and should induce a very definite pattern of expectancies.

Figure 6 shows the pattern of intervals between successive tones in the scale, using the C major scale as an example The number of intervals within the diatonic scale of each type can be summarized (Browne,1981) in what is called the interval vector <2,5,4,3,6,1>. The first entry gives the number of intervals that are minor seconds (m2), the second entry gives the number of intervals that are major seconds (M2), and so on. This vector has the remarkable property that each entry in the vector is a different number, although this seems unlikely to be psychologically significant. What may be significant, however, is the relatively rare appearance of certain intervals, particularly the tritone (which appears once) and the minor second (which appears twice). A corollary of this is that these intervals are contained in relatively few scales. Table 1 shows how many keys have scales containing the intervals that begin with the tone C. The interval C C#/Db is in two scales, Db major and Ab major. The interval C D is in the scales of C, Eb, F, G, and Bb major, and so on. The intervallic-rivalry model (Butler,1989; Brown et al.,1994) builds on the idea that intervals contained in fewer scales carry more reliable information about possible keys. The model in its present elaboration (Brown et al.,1994, p. 372) consists of three hypotheses. These will be given here exactly as stated.




| | |
|---|---|
| Minor Second (m2) | EF, BC |
| Major Second (M2) | CD, DE, FG, GA, AB |
| Minor Third (m3) | DF, EG, AC, BD |
| Major Third (M2) | CE, FA, GB |
| Perfect Fourth (P4) | CF, DG, EA, GC, AD, BE |
| Tritone (TT) | FB |

*Figure 6: Shows the pattern of major seconds (M2) and minor seconds (m2) between successive tones in the diatonic scale: M2, M2, m2, M2, M2, M2, m2. The pattern is shown with reference to the tonic of C. The figure lists the intervals of each size contained in the diatonic scale.*

The first hypothesis is:

**Intervallic-Rivalry 1 (Primacy):** In evaluating rival candidates for the tonic, listeners are biased to assume that the first tone in a musical event is the tonal center, until a better candidate replaces it.

This hypothesis predicts that the first tone sounded will be interpreted as the tonic. In other words, listeners will assume the key in which the first tone is the tonic. The model does not specify the conditions that require a shift to a different tonic. One possibility is that a new tonic is chosen if a tone is sounded that is not in the diatonic scale of the first tone (this is the assumption of the keyfinding algorithm of Longuet-Higgins and Steedman,1971, for example). A final issue concerns the phrase "until a better candidate replaces it." It is unclear whether or not the model assumes that the alternative tonic needs to be sounded before it replaces the initial tone. These issues will be addressed by the present data.

The second hypothesis is:

**Intervallic-Rivalry 2 (Rare Intervals):** In finally determining a tonal center, listeners rely more on rarer than on common intervals among pitches, those that unambiguously correlate with a single diatonic set, because they provide the more reliable key information.

When only three tones are sounded, as in the present experiment, the only case that results in a single diatonic scale is when the three tones contain a tritone. For example, suppose the tritone consists of the tones C and F#/Gb. If the third tone is any one of the tones G, D, A, E, or B, the key must be G major If the third tone is one of the remaining tones, F, A#/Bb, D#/Eb, G#/Ab, or C#/Db, the key must be C# major (or equivalently, in equal-tempered tuning, Db major). For the minor second, no third tone (other than one forming a tritone with one of the tones) results in a single diatonic scale.



The third hypothesis is:

**Intervallic-Rivalry 3 (Temporal Order):** In relying on rarer intervals, listeners are more accurate in detecting a correlation between a rare interval and the key of the musical event containing it when the pitches that outline the rare interval appear in a temporal order implying goal-oriented harmonic motions commonly encountered in tonal music.

Recall the tritone is the only rare interval that, with the addition of a third tone, specifies a single key. For this interval, the goal-oriented harmonic motion referred to contains the fourth scale tone followed by the seventh scale tone (Brown et al.,1994, p 375). Thus, the tonal implication of a tritone is hypothesized to be stronger for the key in which it appears in this order (fourth degree followed by the seventh degree) rather than the reverse (seventh degree followed by the fourth degree). For the tritone C F#/Gb, for example, the implication for G major should be stronger than the implication for C#/Db major. Detailed predictions of each of these three hypotheses will be tested with the experimental data.

## Method

**Subjects.** Sixteen members of the Cornell University community were paid $7 for their participation. The subjects were all experienced musically. They had taken an average of 9.7 years of vocal or instrumental instruction, and had participated in musical activities for an average of 17.4 years. All but two were currently involved in some musical activity, and all but two had at least one course in music theory. None reported absolute pitch.

**Apparatus.** Stimuli were programmed on a Macintosh IIcx computer using the MAX software. The computer was connected through an Apple MIDI interface to a Yamaha TX816 FM (frequency modulation) tone generator. The stimuli were presented with a Yamaha Power amplifier (P2150) and a Yamaha 1204 MC series mixing console through a single JBL Model 4312A loudspeaker at a comfortable listening level. Listeners recorded their responses by moving and clicking on the mouse of the computer.

**Stimulus materials.** Each trial consisted of three consecutive tones sounded with the timbre of a piano. The first two tones were the context interval, the third was the continuation tone. The inter-onset interval between the first and second tones was 700 msec; the inter-onset interval between the second and third tones was 1400 msec. All tones were 600 msec in duration. The context intervals ranged from a descending major seventh (M7 = -11 semitones) to an ascending major seventh (M7 = 11 semitones). All context intervals began on middle C (C4 = 262 Hz). The continuation tones were the 25 chromatic scale tones in a two-octave range centered around the midpoint of the two tones of the context interval. All together, there were 23 blocks of trials, corresponding to the 23 context intervals. (Because of a programming error, two additional blocks were included with context interval sizes of 12 and 13 semitones; they were not included in the analysis.) Each block of trials began with four warm-up trials with randomly selected continuation tones. These were followed without a break by the 25 trials corresponding to the 25 continuation tones which were presented in random order. The blocks of trials were presented to subjects in different random orders.

**Procedure.** The experiment lasted somewhat longer than an hour and a half, and was divided into two experimental sessions conducted on different days. Listeners, who were tested individually, were given the instructions in written form. They were told that they would hear a two-tone interval followed by a third tone, and that they were to judge how well the third tone fits their expectancies about what might follow the interval in a melody. Three controls were displayed on the computer screen. They clicked on the top "button" to start the trial, adjusted the position of a vertical "slider" to indicate their judgment of the continuation tone, and then clicked on the bottom "button" to record their responses. One end of the slider was labeled "very good"; the other end "very poor." The position of the slider was coded by the computer as a number from 0 to 127. The first experimental session began with practice trials to permit subjects to become familiar with the procedure and ask any questions they might have about the instructions.

### Results

**Overview of the analysis.** The primary focus of the analyses will be on the ratings of the continuation tones averaged across listeners because consistent intersubject agreement was observed. Of the 120 intersubject correlations, all but 17 were significant. Individual differences will be considered again after the main analyses are presented. The main analyses consider three kinds of factors that influenced judgments in the present experiment: tonal implications, consonance and dissonance, and melodic implications.

**Tonal implications.** A number of steps were taken to analyze the tonal implications of the two-tone context intervals. The first was an exploratory step in which the 25 ratings for the continuation tones for each context interval were correlated with the experimentally quantified tonal hierarchies (Krumhansl & Kessler, 1982) of the 24 major and minor keys. The objective was to discover which, of all possible major and minor keys, correlated most strongly with the data. This gives an indication of the tonal interpretation of the intervals by assessing its influence on expectancies.

The key with the strongest correlation for each context interval is shown in Table 2 together with the value of the correlation. For example, when the context interval was a descending major seventh, C4 C#3/Db3 (-11 semitones), the key whose tonal hierarchy correlated most strongly with the ratings was Db major, and the correlation was .53. (A correlation with 23 degrees of freedom that is greater than .40 is statistically significant at $p < .05$.) As can be seen, the data for most context intervals correlated quite strongly with the tonal hierarchy of some key. There were three exceptions, two of which were the descending and ascending tritones (C4 F#3/Gb3 and C4 F#4/Gb4). In terms of this measure, then, the tritone does not appear to carry strong tonal implications.

Even though all two-tone intervals began on the tone C4, the key with the strongest correlation varied considerably. In only 8 of the 23 cases was C major the key with the strongest correlation. When the second tone of the context interval was not in the diatonic scale of C major, the key with the strongest correlation was never C major, with one exception (the descending tritone, C4 F#3/Gb3). Even in the 13 cases when the second tone was in the diatonic scale of C major, some other key had the strongest correlation in 6 out of 13 cases. The key with the strongest correlation always contained the context interval in its scale, with the exception of the descending tritone, C4 F#3/Gb3. The next column of the table shows the scale tones of the context interval in the key with the strongest correlation. For example, the descending major seventh, C4 C#3/Db3, consists of scale tones 7 and 1 in the key with the strongest correlation, Db major. This suggested that scale membership of the context interval is an important determinant of perceived tonality. In this connection it is interesting to note that in every case at least one of the tones is a goal note in the key, that is, it is scale tone I, 3, or 5.

These observations, and the prior study by Cuddy and Lunney (1995), indicated that tonal implications might be modeled in terms of scale membership. Their tonal region variable coded as 1 the tonics of keys containing the context interval, and coded as 0 all other tones. (The natural form of the minor scale was used.) A predictor variable formed in this way correlated quite strongly with the present data, but a variation of the tonal region predictor resulted in considerably higher correlations. The modified tonal region predictor was constructed as shown schematically in Figure 7. The first step found the keys in which the two tones of the context interval are both diatonic. In the example given, the two tones, C and E, are diatonic in the keys F, C, and G major, and D, A, and E minor. The tonal hierarchies of these keys (using the values from Krumhansl & Kessler, 1982, which are sketched as the jagged lines above the names of the keys) were then averaged to produce the modified tonal region variable. The last column of Table 2 shows the correlations of this variable with the data. As can be seen, this variable correlated strongly with the data for each interval except the two tritones. For all context intervals combined, the tonal region variable correlated ($r(573) = .61$, $p < .0001$) almost as strongly with the data as the key with the strongest correlation ($r(573) = .62$, $p < .0001$). Thus, the model shown in Figure 7 provides

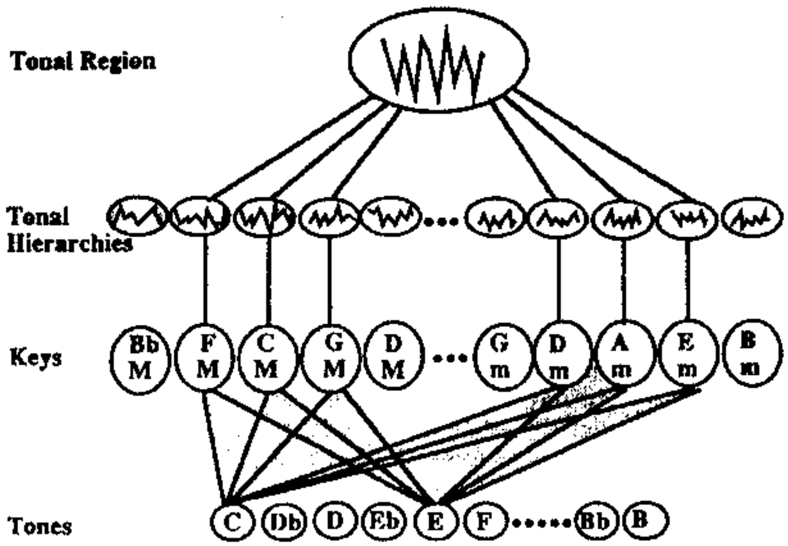



*Figure 7: Sketches the construction of the tonal region variable. The keys containing the context interval are indicated by the solid lines. Their corresponding tonal hierarchies are shown schematically by the jagged lines. The tonal region variable is the average of the probe tone ratings (using the values from Krumhansl & Kessler, 1982) of the keys containing the intervals.*

a principled account of the tonal implications of the intervals. The lowest correlations were for the ascending and descending tritones, C4 F#3/Gb3 and C4 F#4/Gb4, suggesting again that the tonal implication of these intervals are weak or, at least, not governed by the same principle as the other intervals.

Cuddy and Lunney (1995) found another variable, tonal strength, that accounted for additional variance in their data. It was constructed as follows. The two tones of the context interval and the continuation tone were coded with a number representing their relative durations; all other tones were coded as 0 This numerical coding was correlated with the Krumhansl and Kessler (1982) tonal hierarchies for all major and minor keys. The highest correlation for each combination of context interval and continuation tone was used as the value of the tonal strength variable for that combination of tones A tonal strength variable was constructed in this way for the present experiment but did not significantly improve the fit to the data over the modified tonal region variable developed here. Thus, the most satisfactory account found here for the tonal implications of the intervals was the average of the tonal hierarchies of the keys containing the context interval. The tonal implications of the tritone will be considered again later.



**Consonance, unisons, and octaves.** Initial inspection of the data showed relatively high ratings for continuation tones forming consonant intervals with the first tone of the context interval (C4) Closer inspection showed that this was true also for the interval between the second tone of the context interval and the continuation tone. A variable coding consonance was constructed for intervals initiated by both first and second tones and terminated by the continuation tone. The values of the variable were based on empirical and theoretical values of consonance (from Helmholtz,1863/1954; Malmberg, 1918; Hutchinson & Knopoff,1978; Kameoka & Kuriyagawa,1969). Krumhansl (1990 a, p. 55 ff) showed these were highly correlated with one another. The values from each source were normalized (and where necessary reversed so that high values correspond to consonant intervals), and then averaged Octave equivalence was assumed; for example a minor ninth was assigned the same value as a minor second, etc. These two consonance variables were entered into a multiple regression together with other variables to be described below. The results are shown in Table 3, which gives the standard value of the regression weights and the probability for each of the variables.

The effect of consonance was highly significant for the interval initiated by both the first and second tones of the context interval and terminated by the continuation tone These variables, however, did not account for two other effects evident in the data. Continuation tones that repeated the second tone of the context interval received relatively low ratings (similar to the effect found in Krumhansl,1991,1995), and continuation tones an octave away from the second tone of the context interval received relatively high ratings To account for these effects, two other variables were entered into the model. The unison variable coded as 1 the continuation tones identical to the second tone of the context interval; all other tones were coded as 0. The octave variable coded as 1 the continuation tones an octave away from the second tone of the context interval; all other tones were coded as 0 Both these variable were highly significant in the multiple regression, as seen in Table 3.

**Proximity and registral return.** The first two principles of the implication-realization model (Narmour,1990) to be considered are proximity and registral return. Proximity refers to the size of the realized interval which, in the present experiment, corresponds to the interval between the second tone of the context interval and the continuation tone. In previous tests of the model (Krumhansl,1991,1995; Cuddy & Lunney,1995), the principle was coded as shown at the top left of Figure 8. Various alternative formulations were tested with the present data, including linear and low-order polynomial functions. The linear function shown at the top right of Figure 8 provided the most satisfactory and parsimonious account of the effect of the distance between the second tone of the context interval and the continuation tone It should be noted that the crossing point of the line and the horizontal axis was set arbitrarily to six semitones (the tritone) to match the initial portion of the original formulation; any other decreasing linear function would make an equal

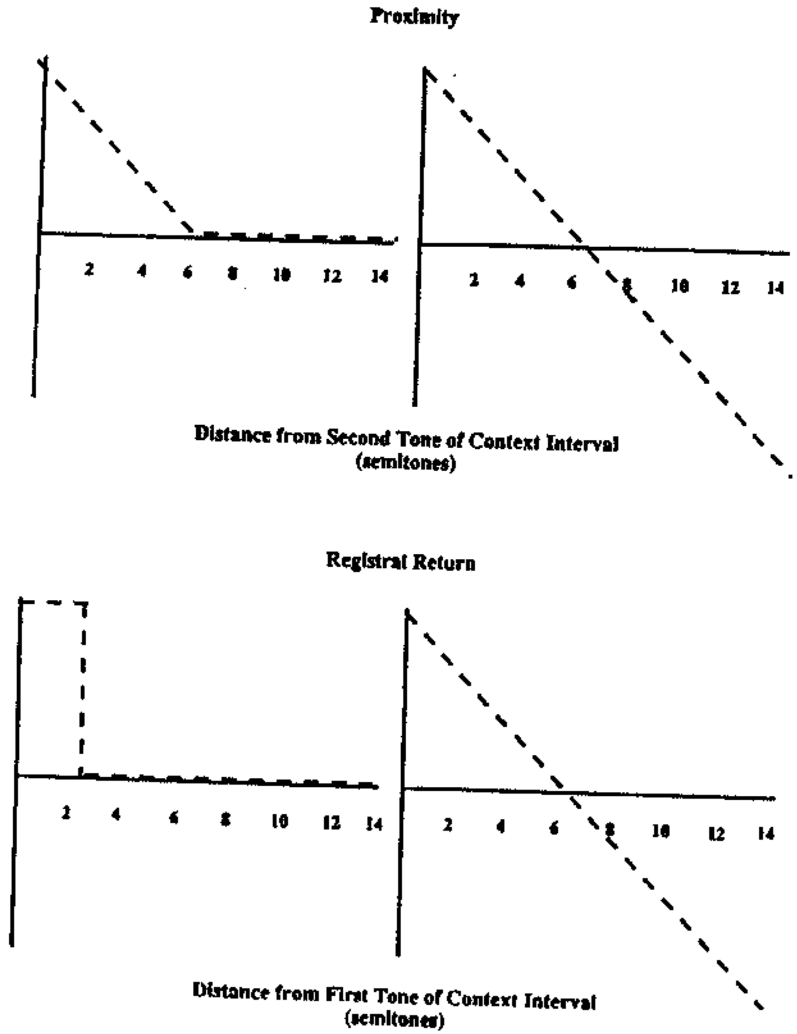



*Figure 8: Shows on the left how the two principles of proximity (top) and registral return (bottom) were originally formulated in the implication-realization model (Narmour, 1990). The corresponding figures on the right show the modification of the principles suggested by the data of the experiment.*

contribution to the fit of the data. Thus, the present data do not support the implication-realization model's sharp distinction between proximate and non-proximate intervals; the best-fitting function was simply a decreasing linear function of interval size.



Registral return refers to the size of the interval formed by the first tone of the implicative interval and the second tone of the realized interval. In the present experiment, this is the interval between the first tone of the context interval and the continuation tone. Previous applications coded this principle as shown at the bottom left of Figure 8. However, the present data did not support the sharp distinction between intervals that are less than or equal to a major second (M2), and larger intervals. Rather, a linear decreasing function over the entire range provided the best account. Again, the crossing point at six semitones is arbitrary; it was chosen to match the distance function for proximity. As can be seen in Table 3, proximity (distance from the second tone of the context interval) had a considerably stronger effect (standard value = 57) than registral return (distance from the first tone of the context interval, standard value = .19).

**Registral direction, closure, and intervallic difference.** These three principles of the implication-realization model (Narmour,1990) have a complex pattern of interrelationships with one another which the following analyses sought to disentangle. Consider first the principle of registral direction which governs the expected direction of the realized interval relative to the direction of the implicative interval. Recall that small implicative intervals imply same direction, and large implicative intervals imply different direction. Figure 9 summarizes this principle in graphical form. The vertical axis represents the size of the implicative interval in semitones; the horizontal axis represents the size of the realized interval and its direction (same or different) relative to the direction of the implicative interval. The combinations of implicative and realized intervals that satisfy the principle (small implicative interval, same direction; large implicative interval, different direction) fall in the shaded region. In the present analysis these combinations were coded as 1. Those combinations that do not satisfy the principle (small implicative interval, different direction; large implicative interval, same direction) fall in the unshaded region; these were coded as -1. In order to include the data for the tritone interval context, these were coded a neutral value of 0.

Registral direction, as coded, accounted for a significant amount of variance in the data, as can be seen in Table 3. A further analysis was done to determine whether the tritone is, in fact, the best estimate of the threshold between implication for same direction and implication for different direction. This analysis was performed on the residuals of the regression model with the other seven variables shown in the table. The residuals were correlated with the registral direction predictor for each context interval separately (excluding the tritones, TT, for which the model makes no prediction). The registral direction predictor was confirmed in every case except one, the major seventh, M7. The major seventh context interval, M7, apparently carries strong enough implications for octave completion (that the next tone would be an octave away from the first tone) to suppress the implication for change of direction. No consistent trend in the strength of registral direction was found over the range of context intervals. Thus, the most satisfactory coding for registral direction was as originally formulated in the implication-realization model, with a sharp boundary at the tritone separating implication for same direction and implication for different direction.

Closure, according the implication-realization model, occurs when either direction changes or a large interval is followed by a smaller interval. Closure is strongest when both these conditions obtain. This principle is represented at the top of Figure 10 with three levels: no closure (white region, neither condition obtains), moderate degree of closure (gray region, one condition obtains), and strong degree of closure (black region, both conditions obtain). Closure can be decomposed into the two all-or-none components shown below, and these were tested separately. The first component, shown at the center, corresponds to a change of direction for all implicative intervals. As would be expected given the analysis just described for registral direction (compare Figure 9), no overall support for this component of closure was found.

The second component of closure, shown at the bottom of Figure 10, corresponds to cases in which a relatively large implicative interval is followed by a smaller realized interval. A regression analysis using the residuals from the eight variable model in Table 3 found no support for the principle as originally formulated. The analysis used a variable that coded those combinations of tones in the shaded region as 1, and other combinations as 0. Additional analyses looked for effects of a generalized formulation of this component using the absolute difference between the size of the implicative

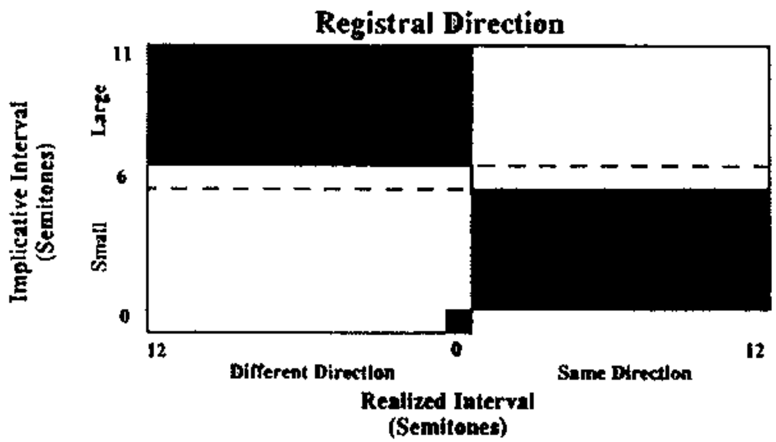



*Figure 9: Shows the principle of registral direction of the implication-realization model (Narmour, 1990). The vertical axis represents the size of the implicative interval in semitones; the horizontal axis represents the size of the realized interval and its direction (same or different) relative to the direction of the implicative interval. The shaded region shows the model's predictions: small implicative intervals (5 semitones, P4, or less) imply same direction, and large implicative intervals (7 semitones, P5, or more) imply different direction.*



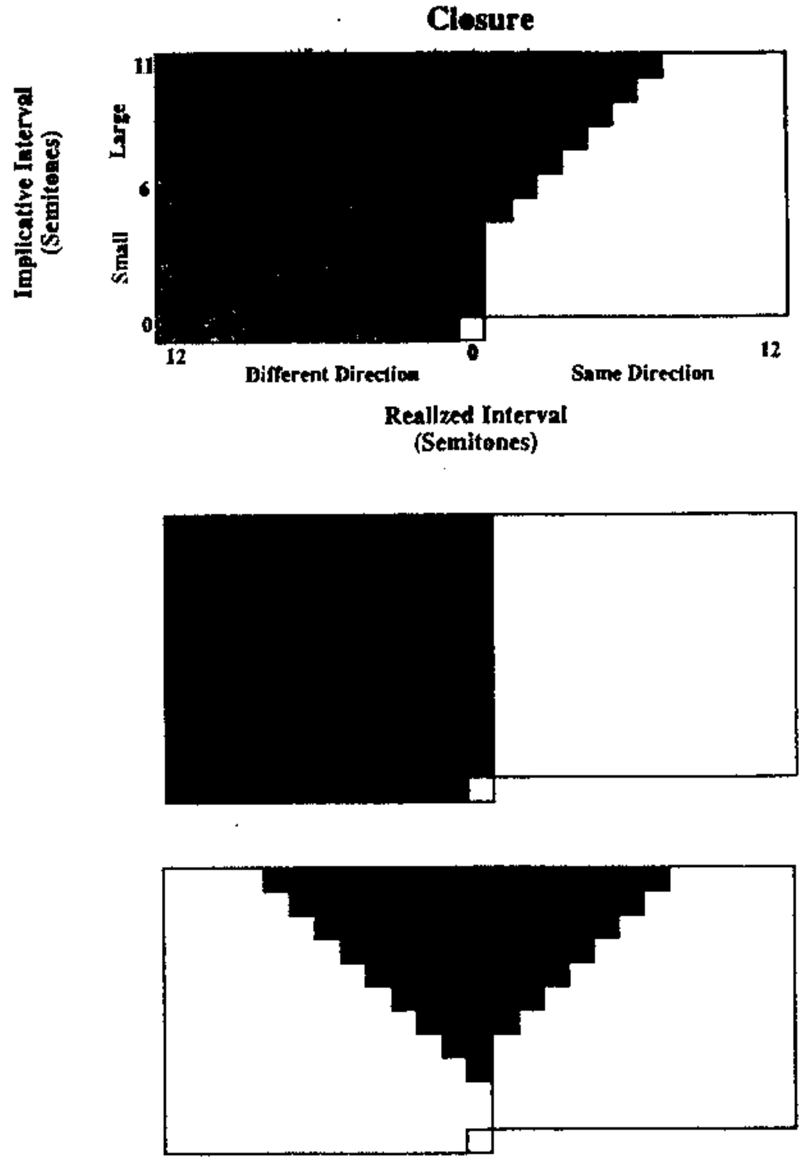



*Figure 10: Shows the principle of closure of the implication-realization model (Narmour, 1990). Closure occurs either when implicative and realized intervals are in different directions (center), or a large interval is followed by a smaller interval (bottom). The text gives the precise specifications of these terms.*

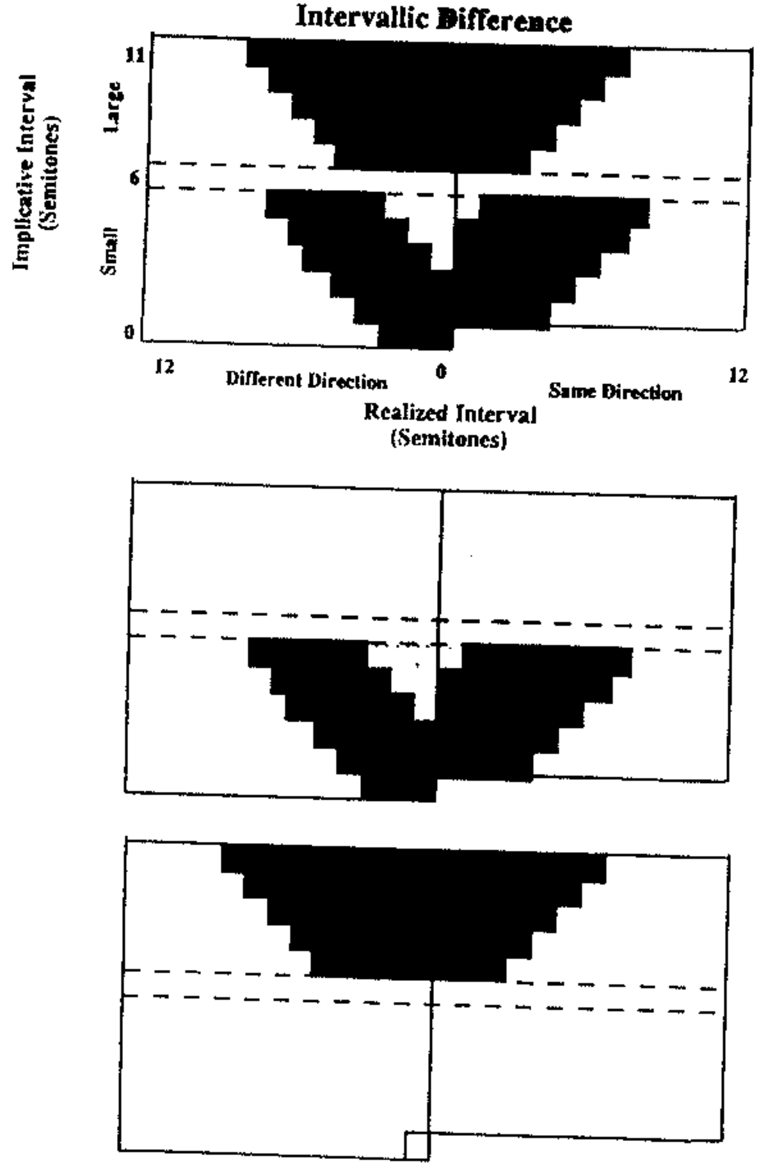



*Figure 11: Shows the principle of intervallic difference of the implication-realization model (Narmour, 1990). For small implicative intervals (center), the principle is satisfied when the realized interval is similar in size. For large implicative intervals (bottom), the principle is satisfied when the realized interval is smaller in size. The text gives the precise specifications of these terms.*



interval and the size of the realized interval. These analyses were run separately for each implicative interval, and no systematic patterns were observed. Thus, the present data did not support the principle of closure, either as originally formulated or as generalized in this way.

The final principle of the implication-realization model is intervallic difference. It, too, can be broken down into two components, as shown in Figure 11. The first component, shown at the center, concerns small implicative intervals. For these, the principle is satisfied when the realized interval is similar in size to the implicative interval. The second component, shown at the bottom, concerns large implicative intervals. The principle is satisfied when the realized interval is smaller in size than the implicative interval. Note the similarity between this second component and the component at the bottom of Figure 10. As would be expected given the analyses just described, no support was found for the second component. Nor was any support found in similar analyses for the first component of intervallic difference which governs small implicative intervals, or for a generalized notion of interval similarity as a function of the difference between the absolute sizes of the implicative and realized intervals. Thus, no support was found for the principle of closure either as originally formulated or as generalized.

**The eight variable model and individual differences.** The present data supported three of the bottom-up principles of the implication-realization model (Narmour, 1990): proximity, registral return, and registral direction. No support was found for either closure or intervallic difference. Additionally, the best fitting coding of the proximity and registral return principles did not correspond to the model's original formulation. Rather, both were modeled better as a linearly decreasing function of interval size. The most satisfactory account of the data from the present experiment averaged across listeners was the eight variable model shown in Table 4 with the variables coded as described in the text and figures. This model adds variables coding effects of tonality, consonance, unisons and octaves to the variables derived from the implication-realization model.

The eight variable model was tested against the data for the 16 individual subjects. The multiple regressions for individual subjects averaged $R(8, 566) = .48$ (range .19 to .72), and all but one was significant at $p < .0001$. The remaining subject's multiple correlation was significant at $p = .01$. That subject's data were dominated by two variables; the consonance of the interval formed by the first tone of the context interval and the continuation tone, and the distance between the second tone of the context interval and the continuation tone (proximity). In addition, that subject was involved in 10 of the 17 nonsignificant intersubject correlations. Thus, with the exception of this one subject, consistent intersubject agreement was found and the regression model provided a good fit of the model at the level of the individual subjects' data. The regression weights for each variable were significantly different (at $p < .01$) from zero (as shown by t-tests) except for the variable coding unisons (although it approached significance at $p = .063$, one-tailed). This exception suggests that individuals adopted different strategies for continuation tones that repeat the last tone of the context interval. No systematic relationships were found between the fit of the model to the data of individual subjects and any aspect of their musical backgrounds. However, it should be recalled that the subject group was restricted to relatively experienced musicians.

**Aplication of the eight variable model to other data sets.** Because the eight variable model was developed in connection with the present data, it is important to determine how well it can account for the data from other experiments. The data sets of Krumhansl (1991,1995) and Cuddy and Lunney (1995) were reanalyzed for this purpose. The continuation tones used in those studies did not coincide exactly with those used in the present study, so the subsets contained in the present experiment was used here. The first experiment (Krumhansl,1995) used excerpts from British folk tunes; the continuation tones were diatonic scale tones. The second experiment used excerpts from atonal songs; the continuation tones were chromatic scale tones. The third experiment used excerpts from Chinese folk songs; the continuation tones were pentatonic scale tones. The context intervals in the Cuddy and Lunney (1995) experiment were ascending and descending major seconds, minor thirds, major sixths, and minor seconds; the continuation tones were chromatic scale tones Two groups of listeners participated in each of the four experiments who varied in terms of either their musical training or their familiarity with the style. Agreement between groups, however, was strong in all cases.

Table 4 shows the fit of the eight-variable model to these four sets of data and compares it with the previous models based on the original formulation of the implication-realization model. In all cases, the eight-variable model developed here gave a higher multiple correlation, and all three principles of the implication-realization model, as modified, were individually significant. The other variables, however, were somewhat less consistent across experiments. As would be expected for the atonal song contexts, the tonal region variable was not significant. Also, consonance was relatively weak in the experiment using British and Chinese folk songs, probably because the continuation tones were selected from diatonic and pentatonic scales, producing a predominance of consonant intervals. Overall, the eight-variable model provided a good account of the data in all four experiments The present results correlated strongly with those of Cuddy and Lunney (1995), with a correlation of $r(177) = .80$, $p < .0001$.

**Tonal implications of the tritone context.** The final analyses were directed at understanding better the tonal implications of the tritone interval. Recall that by two measures discussed previously the tonal implications of this context interval were relatively weak. First, no key had a tonal hierarchy that correlated strongly with the data for these contexts. The highest correlation for C4 F#3/Gb3 was with C major ($r(23) = .39$); the highest correlation for C4 F#4/Gb4 was with G major ($r(23) = .28$). Second, the tonal region variable also had weak correlations with the data for these context intervals



($r(23) = .28$ and .42, respectively). These two measures suggest that, unlike the other intervals included in the study, the tritone interval does not induce listeners to expect tones in the keys containing it.

To look at the data for the tritone more directly, the top of Figure 12 displays the average ratings for each continuation tone in the chromatic scale following the tritone contexts, C F#/Gb. The values shown assume octave equivalence, thus the data were collapsed across octaves. For comparison, the middle and bottom graphs show the corresponding data for the context intervals of C E and C F. As can be seen, the values for the tritone context were considerably less variable. As a way of quantifying the amount of variability, the standard deviations were computed for each interval. The standard deviations for the tritone contexts were two of the three smallest values for the 23 context intervals. This lack of variation suggests why the ratings did not correlate strongly with either the tonal hierarchies or the tonal region variable.

This lack of variation may be due to the fact that any three tones that include a tritone are in the scale of some key, unlike any other context interval. Thus, the ratings of all continuation tones following the tritone context interval may be relatively high compared to other context intervals. To test this, the ratings for the tritone contexts were compared with the average ratings for all contexts exclusive of the tritone. No evidence was found for uniformly high ratings for the tritone contexts. The average rating for the tritone contexts was 64.8, and the average rating for the contexts exclusive of the tritone contexts was 64.3, a nonsignificant difference, $t(49) = .394$, $p = .70$. Thus, by this measure also the tonal implications of the tritone appear to be weak.

The final analysis considered effects of the scale positions of the tritone. Brown et al. (1994) proposed that the tonal implications of tritones that are interpretable as scale tones 4 - 7 are stronger than those interpretable as scale tones 7 - 4. In the present context, this predicts that the tonal implications should be weighted toward the key of G major (in which the interval C F#/Gb corresponds to scale tones 4 - 7) rather than C#/Db major (in which it corresponds to scale tones 7 - 4). Inspection of Figure 12 supports this. The average rating for G, 73.7, is relatively high (following only the tones C and F#/Gb that are actually sounded in the context), and is higher than the rating for C#/Db, 62.8, the alternative tonic. To explore this effect further, the data for all continuation tones that are in the scale of G major (in which the tritone is scale tones 4 - 7) were compared with the data for all continuation tones that are in the key of C#/Db major (in which it is scale tones 7 - 4). The ratings for the former averaged 69 3 and the ratings for the latter averaged 63.9, a difference that was marginally significant (using a 1-tailed test), $F(1,56) = 2.58$, $p = 057$. Thus, the results weakly supported the proposal that the tonal implications of 4 - 7 progressions are stronger than the tonal implications of 7 - 4 progressions.

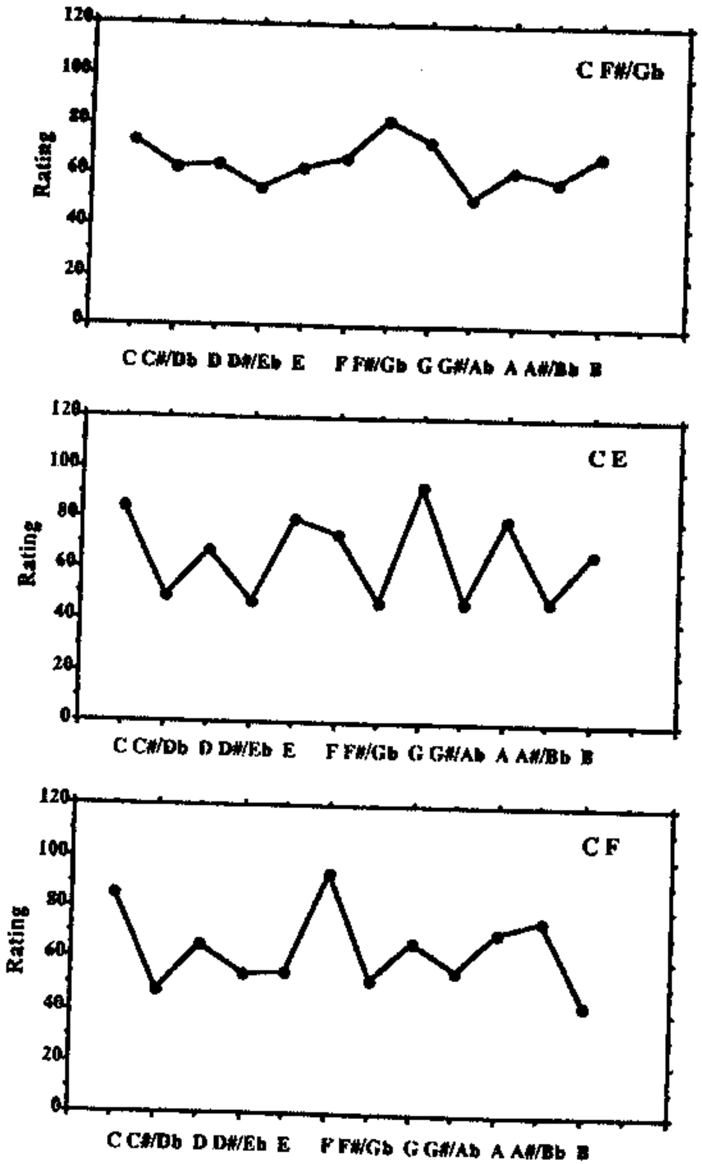



*Figure 12: Shows the ratings for the continuation tones for three context intervals averaged across octaves. The top panel shows the relatively flat pattern found for the tritone, C F#/Gb. The middle and bottom panels show for comparison the ratings for the context intervals C E and C F, which correlated most strongly with the tonal hierarchies of C and F major, respectively.*



### Discussion

The expectancy data of this experiment revealed three different kinds of factors. First, listeners interpreted the tones in terms of their tonal functions in musical keys Second, listeners responded to the consonance of the continuation tones and the context intervals. Third, the listeners showed influences of perceptual organization, in particular, principles of proximity and good continuation. The data gave rise to a quantitative model that determined the relative strengths of these different factors. In addition, two specific music theoretical proposals were examined. The intervallic-rivalry model (Butler,1989; Brown, et al.,1994), makes predictions concerning tonal implications of intervals, focusing on the rare intervals in the diatonic set The implication-realization model (Narmour,1990), makes predictions concerning how general principles of perceptual organization might contribute to melodic expectancies. The results suggest qualifications and modifications of both models.

The ratings of the continuation tones showed that simple two-tone intervals gave rise to strong tonal interpretations (with the exception of the tritone as discussed later). This was the second most powerful single variable (after proximity) found in the analysis of the data. This effect was modeled successfully by a quantitative variable, called tonal region, which was an elaboration of the variable developed by Cuddy and Lunney (1995). The tonal region variable developed here determined all diatonic scales containing the context interval. The tonal hierarchies of these keys (using the values from Krumhansl & Kessler,1982) were averaged to produce a composite variable for the tones that might be expected in those keys. That expectancies for continuations might be generated in this way can be understood because the tonal hierarchies correspond strongly with the probability distributions of tones in musical compositions (Knopoff & Hutchinson,1983; Krumhansl,1990 a, p. 66 ff.) In other words, the tonal hierarchies specify the probability that different tones occur in the key contexts.

The tonal implications of the context intervals were also remarkably labile. There was little evidence that listeners assumed the first tone of the context interval, C, was the tonic. For only a minority of the context intervals did the ratings of the continuation tones correlate most strongly with the tonal hierarchy of C major. Even when the second tone of the context interval was also in C major (and hence there was no necessity to shift to another key), the key whose tonal hierarchy correlated most strongly with the data was often not C major. Thus, this experiment found little to support the first hypothesis of the intervallic-rivalry theory (Brown et al.,1994), the primacy hypothesis, that the first tone is assumed to be the tonic until a "better candidate replaces it." Moreover, the tonic of the key whose tonal hierarchy correlated most strongly with the data had often not been sounded in the context. This suggests that tonal interpretations require only a minimum of perceptual information; the tonic of the key need not be heard.

To return to the tritone, one advantage of the comprehensive sampling of the context intervals in the present experiment is that the tritone can be compared with a large number of other intervals. The results showed the tritone has weak tonal implications relative to other intervals. First, of all twenty-three context intervals, the tritone was among the weakest in evoking a response pattern that correlated with the tonal hierarchy of any key. Second, the tonal hierarchy predictor, described above, was weakest for the tritone. Third, the ratings for continuation tones following the tritone context were relatively uniform, unlike those following other intervals. In other words, the pattern of expectancies was much less defined for the tritone than for other intervals. Finally, even though all three tone patterns containing the tritone are in the diatonic scale of some key, the ratings for the tritone context interval were not higher than those for other context intervals. In sum, the present results find no support for the second prediction, rare intervals, of the intervallic-rivalry model (Brown et al.,1994).

These findings are consistent with previous results. Brown and Butler (1981; Butler & Brown,1984) asked musicians to identify a possible tonic given three-tone contexts. Responses were less accurate when the context contained the tritone (83% in Experiment 1; 91% in Experiment 2) than when it did not (96% in Experiment 1; 98% in Experiment 2). Even when corrected for guessing (assuming the worst possible case of six tonics for contexts not containing the tritone, see Table 2), the resulting values are lower for contexts containing the tritone (84% in Experiment 1; 90% in Experiment 2) than for contexts not containing the tritone (92% in Experiment I; 96% in Experiment 2). In another test, Cuddy and Badertscher (1987) compared three contexts. a major triad, a minor triad, and a diminished triad (which contains the tritone). These contexts were followed by probe tones (using the method of Krumhansl & Shepard,1979; Krumhansl & Kessler,1982). Their listeners generated a much less well-defined pattern for the diminished triad than the other two contexts. Also, the diminished triad resulted in lower judgments of the tonic than the other two contexts. These results have been replicated by Brown et al (1994). Thus, despite the logically appealing special property of the tritone (that it appears only once in a diatonic scale and that, together with any third tone, it uniquely specifies a diatonic scale), the perceptual data currently available do not support its power to evoke strong tonal implications in perception.

The third hypothesis of the intervallic-rivalry model (Brown et al.,1994) did, however, garner weak empirical support in the present experiment. That hypothesis, temporal order, concerns the order of tones in the tritone interval. It predicts that the tritone's tonal implications will be stronger when it appears as the fourth scale tone followed by the seventh scale tone than when it appears in the reverse order. The present study showed two results in support of this hypothesis. First, the rating for the tonic of G major (in which the tritone is the fourth and seventh scale tones) was somewhat higher than the rating for the tonic of C#/Db major (in which it is the seventh and fourth scale tones). Second, the ratings for all diatonic tones in G major were marginally higher than the ratings for all diatonic tones in C#/Db major. The earlier study of Brown and Butler (1981; Butler & Brown,1984) also showed that identification of the tonic was more accurate when the tones appeared in the order of the fourth scale tone followed by the seventh scale tone than the opposite. In sum, temporal order is the only one of the three hypotheses of the intervallic-rivalry model (Brown et al.,1994) that is supported by the data of the present experiment. Krumhansl (1990 b) suggested other perceptual and theoretical reasons why the tritone is, in principle, unlikely to be a strong cue for key identification.



The experiment found that a second factor, consonance, also influenced expectancies. Higher ratings tended to be given to continuation tones that formed consonant intervals with both first and second tones of the context interval. This finding was unanticipated for three reasons. First, interference between near-by harmonics of complex tones, the accepted explanation for dissonance (Plomp & Levelt,1965), arises only from simultaneous tones and not from successive tones such as those used here. Second, implicit in the music perception literature is the assumption that consonance and dissonance are relatively sensory effects that may initially play a role in forming scales and harmonies, as suggested by Helmholtz (1863/1954), but that the interpretation of musical intervals relies on cognitive processes that compare the sounded tones to knowledge representations of musical structures acquired through extensive musical experience. Third, studies of tonality have tended not to find effects of consonance. For example, although the tonal hierarchies of Krumhansl and Kessler (1982) correlate with both consonance and the distribution of tones in tonal music, only the latter had an effect when both variables were considered together (Krumhansl,1990 a, pp. 75-76).

In retrospect, the design of the present experiment was better suited for eliciting an influence of consonance than other studies. Continuation tones were presented over a two-octave range. This allowed a symmetrical pattern to emerge around the reference tones (the first and second tones of the context interval). For example, ratings of tones a minor second, m2, both above and below the first tone of the context interval were low, ratings of tones a perfect fourth, P4, both above and below the first tone of the context interval were high, and so on. In contrast, experiments eliciting the tonal hierarchy have tended to use tones in a single octave (e.g., Krumhansl & Shepard,1979; Castellano, Bharucha, & Krumhansl,1984; Brown et al.,1994), or "circular" tones (also called "Shepard" tones, Shepard,1964) with components sounded simultaneously over a number of different octaves (Krumhansl & Kessler,1982; Krumhansl, Sandell, & Sergeant,1987; Cuddy & Badertscher, 1987). These experimental designs were appropriate for measuring tonal influences of pitch classes (octave equivalent tones) relative to the tonic, but apparently obscured influences of consonance independent of these tonal effects.

The experiments of Krumhansl (1991,1995) and Cuddy and Lunney (1995) did, however, sample continuation tones over a two-octave range. Therefore, consonance might have contributed to the results in a way that was not uncovered in previous analyses. On reanalysis, two of these experiments showed no, or only weak effects of consonance. These two experiments used excerpts from British and Chinese folk songs (Krumhansl 1991,1995) and continuation tones from diatonic and pentatonic scales, respectively. Both of these scales contain a disproportionate number of consonant intervals, restricting the range of consonance in the experiments and therefore possibly reducing the magnitude of its effect. The two other experiments did, however, show an effect of consonance. One (Krumhansl,1995) used excerpts from atonal songs and continuation tones in the chromatic scale. The other, the experiment of Cuddy and Lunney (1995), also showed an effect of consonance.

These findings should revive an interest in consonance independent of other tonal influences. The pattern found in the data, moreover, suggests that one way to disentangle the effects of these factors is to examine symmetrical versus asymmetrical effects around fixed reference pitches. The symmetrical pattern of consonance and dissonance uncovered here is reminiscent of the virtual pitch theory of Terhardt (1974,1984), which has been developed further by Parncutt (1988,1989). This theory posits that pitch perception is influenced not only by harmonics of tones but also by subharmonics that are located symmetrically around the fundamental frequency. Thus, the virtual pitch theory may yield additional insights into how consonance and dissonance can be separated from effects of scale structure, harmony, and tonality.

The third, and final influence on the data of the present experiment came from principles of perceptual organization, particularly proximity and good continuation. Of all the variables examined, the strongest variable was the distance between the second tone of the context interval and the continuation tone. Listeners strongly preferred continuation tones that were proximate to this tone, and the ratings fell off linearly with distance. Distance from the first tone also had an influence, although weaker, and the ratings again fell off linearly. Both these results suggest that a general perceptual principle of pitch proximity is operating in music perception. Numerous other results in the literature suppon this, such as scaling judgments (Levelt, Van de Geer, & Plomp, 1966; Krumhansl,1979), naming and memory errors (Lockhead & Byrd,1981; Klein, Coles, & Donchin,1984; Deutsch,1978), and the segregation of tone sequences into two or more separate patterns or "streams" (Miller & Heise,1950; Bregman & Campbell,1971; Dowling,1973; Van Noorden, 1975). Moreover, the vast majority of intervals used in music are relatively small (e.g., Zipf,1949/1965; Knopoff & Hutchinson,1978). Thus, proximity appears to be one of the strongest, if not the strongest, factor governing the perception of musical intervals.

The results also showed an effect akin to the principle of good continuation, at least for small context intervals. When the context interval was small, listeners preferred continuation tones that continued the direction of the context interval (ascending-ascending, descending-descending, and lateral-lateral). When the context interval was large, however, listeners preferred a reversal of direction. To speculate on a possible basis for this result, the large interval may create a sense of instability that is resolved to some extent when the continuation tone moves back toward the initial pitch level. Thus, this effect might be akin to a principle of symmetry or near-symmetry. These two effects map onto Schmuckler's (1989,1990) effects for linear and gap-fill melodies, using the terminology of Meyer (1973). No effects corresponding to a principle of similarity were found, however. The analysis of the data specifically tested the way in which these Gestalt-like principles are expressed in the five underlying principles of the implication-realization model of Narmour (1990).



The first principle is proximity, which means proximity to the second tone of the implicative interval (the second tone of the context interval of the present experiment). As just indicated, a strong effect of proximity was observed. However, the linearly decreasing function found in the data does not correspond to the distinction made in the model between proximate and non-proximate intervals. According to the model, a boundary falls between the perfect founh, P4, and the tritone, TT, that separates proximate from non-proximate intervals. The present results, however, showed that the proximity effect is graded linearly over the entire range of intervals used in the experiment. This finding is more consistent with a general psychological principle of proximity than with the theoretical proposal for a specifically musical principle of proximity. Thus, although some support was obtained for this first principle, the precise specification of the proximity function was not supported.

The second principle, registral return, refers to cases in which the realized interval returns to the pitch region of the initial tone of the implicative interval. In terms of the present experiment, this refers to the proximity between the first tone of the context interval and the continuation tone. Again, as indicated above, an effect of proximity to the first tone was found. Again, however, the pattern of responses found did not conform to the precise specifications of the implication-realization model. The model considers registral return to be limited to cases in which the relevant tones are within a major second, M2, of one another. The present data showed that the proximity function was considerably broader, again extending over larger pitch distances. So, the second principle, like the first, was partially supported, but the principle as originally stated accounted less well for the data than a simple linearly decreasing function of interval size.

The third principle, registral direction, was confirmed by the data with only one minor qualification. It predicts that listeners expect small intervals (a perfect fourth, P4, or smaller) to be followed by an interval continuing in the same direction, and that they expect larger intervals (a perfect fifth, P5, or larger) to be followed by an interval reversing the direction. The data conformed to these predictions, including the specification of the tritone, TT, as the boundary between intervals implying continuation of direction and intervals implying reversal of direction. The data for the major seventh, M7, was the only case that deviated from predictions. This exception, however, can be accounted for by the strong implication of this interval for octave completion. The present formulation retained the principle as originally stated.

The fourth principle, closure, was decomposed into two separate components and these were tested individually. The first component predicted a general preference for continuation tones reversing direction. The results just discussed for registral direction disconfirmed this prediction; the preferred direction of the continuation tone was either the same or different depending on the size of the context interval. The second component predicted a preference for cases in which a large implicative interval is followed by a smaller realized interval, with the interval sizes specified in detail. The ratings did not correspond to the predictions, nor did they support a generalized notion that listeners prefer sequences in which the second interval is smaller than the first interval. This principle was not included in the final model of the data.

The fifth, and final principle, intervallic difference, also found no support. It predicted that small implicative inteivals imply similarly-sized realized intervals and that large implicative intervals imply smaller realized intervals. The meaning of the terms small, large, similarly-sized, and smaller are defined exactly by the model. The prediction of this principle for large implicative intervals is essentially the same as the second component, just discussed, of the principle of closure, which found no empirical support. The predictions of the intervallic difference principle for small implicative intervals was also tested. The ratings for small context intervals did not conform to the predictions, nor did they conform to a generalized notion of interval similarity. Support for the principle of intervallic difference was weak in previous experiments also (Krumhansl,1991,1995; Cuddy & Lunney,1995), and was not included in the final model.

To summarize these tests of the implication-realization model (Narmour, 1990), the empirical data supported three of the five principles, although a modified formulation of two of them was developed from the data. Two principles were not supported and were not included in the final model The modified principles of the implication-realization model also found consistent support in the reanalysis of earlier data sets (Krumhansl,1991,1995; Cuddy & Lunney,1995) Fortuitously, the three remaining principles are logically and statistically independent of one another This resolves a problem that had plagued the earlier tests of the implication-realization model. With the modification to the principle of registral return, both closure and Intervallic difference became redundant. One advance of the present study, then, was to arrive at a model with a smaller number of principles for melodic implications, and these principles have the desirable property that they are independent of one another.

Taken together, the tests of the intervallic-rivalry model of Brown et al. (1994) and the implication-realization model of Narmour ( 1990) suggests a tendency of music theoretical proposals toward overspecification. At least, the present results suggest that the detailed claims of these models may not be justified on perceptual grounds. The disparity between theoretical claims



and empirical results was greater for the intervallic-rivalry model. The results show that listeners interpret an interval in terms of all its possible tonal functions, and do not necessarily assume that the first tone is the tonic. In addition, the present results, and those of earlier studies, do not find evidence that the rare interval of the tritone provides a clear indicator of key On balance, the results suggest the opposite, that as an isolated interval the tritone is weaker than other intervals. The aspect of the model that did receive support, in both this and earlier studies, is that the tritone when sounded in one temporal order implies a harmonic progression that conveys information about key.

The present experiment also found somewhat mixed results on Narmour's (1990) implication-realization model, although the data generally support the model's claim that bottom-up processes of perceptual organization influence melodic expectancy The results suggest that the specific parameterization of two of the principles, proximity and registral return, may need to be modified. In addition, closure and intervallic difference were not supported. The lack of support for closure can be understood because the instructions asked listeners to judge whether the continuation tone fits their expectancies about what might follow the interval in the melody, not whether it creates a good ending or a complete pattern The lack of support for intervallic difference is more problematic. No aspect of the experimental procedure would seem to work against its influence. Moreover, other previous experiments have found it to be relatively weak also. It should be noted that intervallic difference is one of the two principles on which Narmour's (1990) classification of melodic structures is based. This classification scheme has grown out of extensive music analysis, and may have utility in that context, but the present results suggest caution in motivating it on psychological grounds.

Theorists form generalizations about musical practice through intellectual inspection of music written in particular styles, especially Western art music. They are less concerned with psychological effects, or generalizations across listeners and musical styles. Nonetheless, their proposals are valuable to music psychologists. They challenge experimentalists to devise new methodologies, and to consider conespondences with existing psychological evidence. The two proposals tested here are exemplary for making clear and precise predictions for music perception and cognition. This facilitates transforming the proposals into experimental procedures. It also motivates particular approaches to analyzing the data Psychological research can, in turn, suggest limitations, modifications, and extensions of the proposals, and provide a deeper understanding of music by comparison with psychological phenomena in other domains.

**Table 1**
**Scales that Contain Intervals**

| Interval | Scales Including Interval | | | | | |
|---|---|---|---|---|---|---|
| CC#/Db | Db Major | Ab Major | | | | |
| CD | C Major | Eb Major | F Major | G Major | Bb Major | |
| CD#/Eb | Db Major | Eb Major | Ab Major | Bb Major | | |
| CE | C Major | F Major | G Major | | | |
| CF | C Major | Db Major | Eb Major | F Major | Ab Major | Bb Major |
| CF#/Gb | Db Major | G Major | | | | |
| CG | C Major | Eb Major | F Major | G Major | Ab Major | Bb Major |
| CG#/Ab | Db Major | Eb Major | Ab Major | | | |
| CA | C Major | F Major | G Major | Bb Major | | |
| CA#/Bb | Db Major | Eb Major | F Major | Ab Major | Bb Major | |
| C B | C Major | G Major | | | | |

**Table 2**
**Tonal Implications of Context Intervals**

| Context Interval | Semitones | Key with Strongest Correlation | Correlation | Scale Degrees | Correlation with Tonal Region |
|---|---|---|---|---|---|
| C4 C#3/Db3 | -11 | Db major | .53 | 7-1 | .56 |
| C4 D3 | -10 | G minor | .61 | 4-5 | .60 |
| C4 D#3/Eb3 | -9 | Ab major | .77 | 3-5 | .74 |
| C4 E3 | -8 | C major | .76 | 1-3 | .84 |
| C4 F3 | -7 | F major | .77 | 5-1 | .76 |
| C4 F#3/Gb3 | -6 | C major | .39 | 1-x | .28 |
| C4 G3 | -5 | C major | .63 | 1-5 | .61 |
| C4 G#3/Ab3 | -4 | Ab major | .76 | 3-1 | .71 |
| C4 A3 | -3 | C major | .68 | 1-6 | .63 |
| C4 A#3/Bb3 | -2 | Eb major | .64 | 6-5 | .68 |
| C4 B3 | -1 | G major | .60 | 4-3 | .59 |
| C4 C4 | 0 | C major | .56 | 1-1 | .64 |
| C4 C#4/Db4 | 1 | Db major | .65 | 7-1 | .60 |
| C4 D4 | 2 | C major | .37 | 1-2 | .56 |
| C4 D#4/Eb4 | 3 | Eb major | .70 | 6-1 | .65 |
| C4 E4 | 4 | C major | .74 | 1-3 | .71 |
| C4 F4 | 5 | F major | .69 | 5-1 | .58 |
| C4 F#4/Gb4 | 6 | G major | .28 | 4-7 | .42 |
| C4 G4 | 7 | C major | .67 | 1-5 | .66 |
| C4 G#4/Ab4 | 8 | Ab major | .56 | 3-1 | .62 |
| C4 A4 | 9 | F major | .76 | 5-3 | .67 |
| C4 A#4/Bb4 | 10 | G minor | .45 | 4-3 | .57 |
| C4 B4 | 11 | G major | .50 | 4-3 | .55 |
| All Intervals | | | .62 | | .61 |



**Table 3**
**Multiple Regression of the Eight Variable Model**

Multiple Correlation $R(8, 566) = .83$, $p < .0001$

| Variable | Standard Value | Probability |
|---|---|---|
| Tonal Region | .45 | .0001 |
| Consonance with First Tone | .17 | .0001 |
| Consonance with Second Tone | .13 | .0001 |
| Unison with Second Tone | -.10 | .0003 |
| Octave with Second Tone | .23 | .0001 |
| Proximity | .57 | .0001 |
| Registral Return | .19 | .0001 |
| Registral Direction | .08 | .0007 |

**Table 4**
**Comparison of the Eight Variable Model with Previous Models**

| Context | Eight Variable Model | Previous Model |
|---|---|---|
| British Folk Songs[1,2] | R(8,97) = .86 | R(7,98) = .82 |
| Atonal Songs[2] | R(8,169) = .77 | R(7,170) = .68 |
| Chinese Folk Songs[2] | R(8,105) = .89 | R(7,106) = .82 |
| Context Intervals[3] | R(8,169) = .85 | R(7,170) = .78 |

[1] Data from Krumhansl (1991); [2] Data from Krumhansl (1995); [3] Data from Cuddy and Lunney (1995)

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