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Anchoring Effects in Music: The Resolution of Dissonance

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Most pieces of music induce in the listener a sense that some pitches sound consonant, stable, or final, while others sound more dissonant, unstable, or transient. A psychological account of the intuition that the dissonance of an unstable tone is sometimes "resolved" by following it by a stable tone that is close in pitch is provided. The perceived hierarchy differentiating tones on the basis of stability may be construed as a cognitive schema, which facilitates the encoding of some tones relative to others. A cognitive principle, melodic anchoring, which specifies the ordered relationships (between tones) that govern (i) the activation of one tonal schema over another and (ii) the assimilation or anchoring of unstable tones to the tonal schema once it has been activated is presented. In a forced-choice paradigm, the principle is invoked to predict which chord is perceived to "underlie" a sequence that is tonally ambiguous in all respects except the ordered relationships between its tones. In a same-different task, subjects were presented with a pair of tonal sequences. When a stable tone was replaced by an unstable tone, more confusions occurred when the latter was anchored than when it was not. The accuracy advantage when the unstable tone was in the comparison as opposed to the standard sequence was lower when the unstable tone was anchored than when it was not. Finally, subjects rated how well a sequence and a chord sounded together. Melodies that contained an unstable tone were given higher ratings when the unstable tone was anchored than when it was not. Each paradigm was used to demonstrate first immediate and then delayed anchoring.

Most music consists of a fabric of consonance into which dissonance is woven to varying degrees. Listeners have strong intuitions about how dissonance is used, yet few have any explicit knowledge of it. An unresolved dissonance is heard as a "wrong note," whereas dissonance that is resolved is assimilated to the consonant fabric. A dissonant musical event often has a dynamic quality, inducing an expectation of resolution to a following consonant event. The music-theoretic terms "stable" and

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"unstable" capture this property and have more general application; they will be used in place of "consonant" and "dissonant," respectively. In the context of a given piece of music, the 12 pitches into which the octave is divided are typically perceived in a hierarchy of stability—a tonal hierarchy (Bharucha, 1984; Castellano, Bharucha, & Krumhansl, 1984; Krumhansl, 1979; Krumhansl & Shepard, 1979). After a tonal hierarchy has been established, usually within the first few bars of a piece, an unstable tone seems to interfere or clash with the stable fabric unless it is resolved.

What psychological principles govern the conditions under which resolution is perceived? This paper tests a principle which specifies the ordered or syntactic relationships between tones by virtue of which unstable tones are perceived to be resolved. It is argued that the same principle enables the listener to establish the requisite tonal hierarchy on the basis of ordered relationships alone, when no other cues are available. This is a bootstrapping problem (Deutsch, 1984) which arises at the beginning of a melody whose tonal hierarchy would be ambiguous if not for the ordered relationships between its tones. The proposed principle thus characterizes the tacit knowledge the listener uses to assign each incoming tone to a position of relative stability or instability.

The tonal hierarchies used in Western music are the 12 major and minor keys, and in Indian music are the rāgs and thāts. These hierarchies are internalized by members of a culture, and facilitate the processing of music of that culture. The cognitive structure that incorporates information about a particular tonal hierarchy and uses this information to influence the encoding of music may be thought of as a tonal schema (after Dowling, 1978). The acquisition of tonal schemata may be due at least in part to a person's repeated exposure to a musical form in which certain characteristic subsets of tones are given prominence (Castellano et al., 1984). For listeners familiar with the genre of a particular piece of music, the beginning of a piece activates a particular tonal schema. Once established, the schema influences the perception of stability of tones or chords heard subsequently.

Composers exploit the perceived differences in the stability of tones to serve their esthetic ends. In most music with widespread appeal, unstable tones serve to embellish, ornament, generate variation, or induce in the listener a need for resolution. In these cases, unstable tones are usually employed in a rule-governed fashion. An unstable tone randomly inserted into a sequence of stable tones is likely to clash or interfere with the tonal schema. It will be argued that unstable tones are heard as clashing or interfering with the tonal schema unless they can be assimilated to it, and that assimilation takes the form of anchoring unstable tones to the tonal schema. The principle tested in the following experiments—called *melodic anchoring*—states the conditions under which anchoring can occur: if an unstable tone is followed in the melody by a stable tone and if the two are proximal in pitch, the unstable tone can be anchored to the tonal schema via its privileged pitch relationship to the stable tone.

As an illustration of the failure to anchor an unstable tone, consider a melody left hanging on its penultimate note. There is no sense of finality or completion. The composer has induced strong expectations for something to follow, and these expectations are not fulfilled. The unstable tone is perceived as having a dynamic character, setting up a vector pointing in the direction (ascending or descending) of the expected anchoring. Such tones are said to have an "upward leading" or "downward leading" (Schoenberg, 1954/1969, p.23) dynamic quality. The tone ("ti") that precedes the tonic ("do") in the major or minor scale (do, re, mi, fa, sol, la, ti, do) is called the leading tone because it is heard as leading toward the tonic, which is the most stable tone in the scale. String players often play upward leading tones sharper and downward leading tones flatter to emphasize the sense of an unstable tone demanding resolution to a stable pitch neighbor expected to follow. In Indian classical music the performer teases the audience by prolonging the Indian equivalent of the leading tone ("ni") until he or she is sure that resolution to the tonic ("sa") will elicit exclamations of approval ("vah-vah!") from the audience.

Another familiar manifestation of the perceptual effect of unanchored unstable tones is our uncanny ability to pick out wrong notes. You are in the audience at an amateur recital. You have never heard the piece before, do not consider yourself a sophisticated listener, and have no knowledge of music theory. Yet, in the midst of a lyrical passage you are suddenly acutely aware of a sour note. A professional performer would probably "cover up" this mistake by immediately resolving the wrong note, i.e., following it by a stable tone closest to it in pitch; this would make it seem like ornamentation, or at least reduce its jarring character. The cover up causes the potentially sour tone to be anchored by the stable tone that follows it. The tonal schema is established by what transpires prior to the error; but given this schema, the manner in which the wrong note is perceived is determined by the note that *follows* it.

As early as 1558, Zarlino (1558/1968) prescribed guidelines for the use of dissonance in musical counterpoint. The guidelines most relevant to the present investigation are that a dissonance should be preceded and followed by consonances that are closest to it in pitch, for otherwise "the dissonance is made so noticeable . . . it can hardly be tolerated" (p. 95). What comes *after* the dissonance is, however, more important than what comes before, from the cognitive point of view. The principle of melodic anchoring specifies a constraint only on the pitch distance between an unstable tone and the stable tone that follows. The design of the following experiments permits a comparison of pitch distance effects both before and after the unstable tone. It is hypothesized that for the assimilation of the unstable tone, the decisive pitch distance is the one that follows the unstable tone. Indeed, the writings of Fux (1725/1943), and the structure of most forms of music to date with widespread audiences suggest this conclusion. A composer is of course free to write unstable tones so that they cannot be anchored, so as to produce a desired esthetic effect. Melodic anchoring is not a prescriptive principle, but a psychological one. The appreciation of compositional forms that depart radically from a structure which enables the listener to differentiate tones on the basis of stability and assimilate the unstable ones seems to require considerable intellectual effort. Song writers of most popular music adhere reliably, though perhaps unwittingly, to compositional constraints that have resisted change for centuries. This paper attempts to characterize the tacit knowledge that underlies the strong melodic intuitions of listeners with no explicit knowledge of music theory.

Melodic anchoring is a principle of perceptual organization that seeks to reduce disparate pieces of auditory information to an entrenched schema. Principles that reduce information load by interpreting new information in light of familiar information exist for most cognitive domains, both perceptual as well as semantic (Rosch, 1973). In the visual domain, Rosch (1975) has argued that lines that are horizontal, vertical, or angled at 45° act as cognitive reference points for the perception of lines of other orientations. She also found that focal colors act as cognitive reference points with respect to off-hue colors. The categorization of objects follows similar information reduction principles. Prototypical instances of a category act as organizational foci or cognitive reference points which anchor less typical instances (Rosch, 1975).

A cognitive reference point along a particular dimension is a point in relation to which neighboring points are perceived. The relationship between a cognitive reference point and a neighboring point which it anchors is asymmetric. Rosch found that a line angled at 10° to the horizontal is perceived to be more closely related to a horizontal line than vice versa. Analogous asymmetries were found for the relationships between focal and off-hue colors.

In a tonal context, some tones exhibit the properties of cognitive reference points. Krumhansl (1979) found that stable tones are perceived to be more closely related to each other than are unstable tones, thereby clustering closer together in multidimensional space than unstable tones. The perceived relationship between a stable tone and an unstable tone was found to be asymmetric; they are perceived to be more closely related when the stable tone follows the unstable tone than vice versa. Stable chords also act as cognitive reference points, exhibiting both these properties (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982).

TONAL SCHEMATA

Stability is a concept that music theorists use to articulate their intuitions about the relative finality, degree of resolution, and sometimes, consonance, of tones or chords, once a tonal context has been established. A psychological characterization is possible in terms of the spatial model used in the studies cited above. Two properties define perceived stability. First, the greater the stability of some tones or chords relative to others, the more closely they will cluster together in multidimensional space, forming cognitive reference points. Second, the greater the difference between the stability of two tones or chords, the stronger their perceived asymmetry. Changing the musical context (changing the key, changing the diatonic scale upon which the piece is based), causes the space to be distorted so that different tones and chords cluster together, creating new organizational foci or cognitive reference points, while leaving the space topologically unchanged (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982). Changes in the perceived stability of tones and of chords are closely linked (Krumhansl & Kessler, 1982), because chords are the simultaneous sounding of tones. As a shorthand, the distortion of psychological tone-space and chord-space by creating focal points around which stable tones or chords locate themselves, along with the inducement of asymmetries, will be described as the *engagement or activation of a tonal schema*. A tonal schema specifies a hierarchy of stability (a tonal hierarchy) of all possible tones and chords (see Bharucha, 1984). Psychological tone-space is conically configured with the most stable tones nearest the vertex (Krumhansl, 1979). Psychological chord-space, which is toroidal (Krumhansl & Kessler, 1982), distorts so that chords are drawn closer together or pushed further apart depending upon how closely or distantly related they are to the key of the context (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982).

The hierarchies of stability specified by a tonal schema must form the basis for any real-time processing (Lerdahl, 1983, August) that analyzes a piece of music into the event hierarchies described by Deutsch and Feroe (1981) and Lerdahl and Jackendoff (1983). Indeed, the ongoing assignment of each incoming tone or chord to a position of prominence or subordination presupposes a representation specifying the relative stability of the building blocks of the genre of music in question, which in Western music are the 12 chromatic tones and all major and minor chords (see Bharucha, 1984, for a discussion of the relation between event hierarchies and tonal hierarchies).

Once a tonal schema is activated by the prior musical context, subsequent tones and chords are perceived in terms of it. Tones that locate themselves in the central cluster caused by the activation of a tonal schema can serve as anchors for unstable tones that are close to them in pitch. A tone distant from the central cluster would not be easily assimilated to the tonal schema unless it is anchored. In Western music, which is based on harmony, only one chord (from among the chords that are centrally clustered for that key) is in focus at any given time. This is the chord that accompanies or is suggested by the current segment of the melody. The component tones of the currently heard or implied chord are more stable than the other diatonic tones.

STABILITY

Most forms of music are tonal in the most general sense that they will engage a tonal schema by virtue of the selection and temporal ordering of musical elements. In any given musical composition, the tones used most often are a proper subset of all the available tones. In Western music, a piece said to be "in the key of C major," for example, would typically contain the 7 tones of the C major scale (C, D, E, F, G, A, B) considerably more often than the remaining 5 tones (C#, D#, F#, G#, A#) of the available set of 12 tones per octave. The top of Fig. 1 shows the set of 12 tones into which the octave is divided. This is called the chromatic scale. Below that is the C major scale, which consists of a

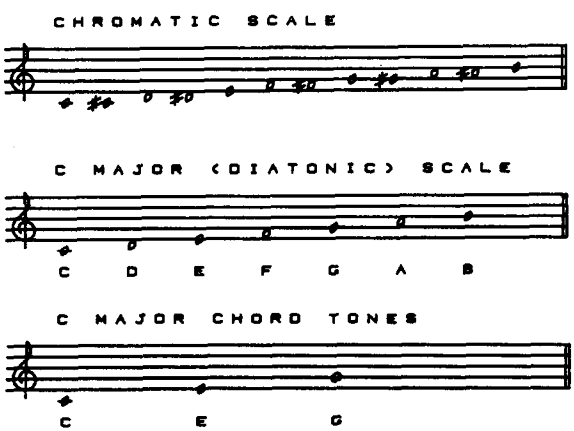

FIG. 1. Hierarchy of stability of tones when a C major context has been established. The chromatic scale (top) specifies the 12 tones into which the octave is divided. Tones in the C major scale (diatonic tones) are more stable than the remaining 5 (nondiatonic tones). If a C major chord is being heard or implied, its component tones (chord tones) are more stable than the remaining tones (nonchord tones).

subset of 7 of the 12 chromatic tones. Any one of several possible subsets may be used. The alphabet (C) indicates the tone on which the scale is based (called the tonic, the most stable tone in the scale). ''Major'' or ''minor'' indicates the relative spacing of the tones (i.e., which elements of the chromatic scale, relative to the tonic, are represented). The major and minor scales in Western music are called diatonic scales. In and of themselves, the 12 tones of the chromatic scale are perceived as equally stable. The use of a diatonic scale (major or minor) renders those 7 tones more stable than the remaining 5. Many other cultures have scales that pick out a subset of the chromatic tones (e.g., the ''thāt'' of Indian music).

Of the seven diatonic tones upon which any given Western piece is based, the three tones comprising the chord in focus are more stable than the other diatonic tones. These three tones are called chord tones. Figure 1 shows the chord tones for the C major chord. The alphabet name of the chord (C) indicates the tone upon which the chord is built (the root of the chord). The other two component tones of the chord are selected by the following procedure: skip the tone following the root in the diatonic scale and pick the next tone (E); then skip the following tone and pick the next (G). Similarly, the chord built upon G would have G, B, and D as its chord tones.

A perceived hierarchy of stability also exists for chords (or more precisely, chord functions). In the context of a given key, the most frequently used chords are those built upon the seven tones of the diatonic scale. The chords based on the first (tonic), fourth (subdominant), and fifth (dominant) degrees of the diatonic scale are more stable than the others. A classical symphony would, for example, usually end with the dominant followed by the tonic; both are stable, but the dominant is not stable enough for an ending and must be anchored by the tonic. The perception of this hierarchy of stability of chords has been demonstrated experimentally (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982). The perceived relationship between the stability of chords and of tones has been investigated by Krumhansl and Kessler (1982).

HARMONY UNDERLYING MELODY

Melody and harmony are inextricably interrelated in most Western music. At the risk of oversimplification, it is possible to identify four basic ways in which melody and harmony are usually combined. First, chords may be used to accompany or provide a background for a melody. This is the standard format in most popular music. Second, in a sequence of chords, the sequence of tones formed by the highest tone of each chord is often heard as a melody. Hymns often have this character. Third, several melodies played simultaneously may instantiate a chord sequence, as in counterpoint. This would occur, say, when different instruments in an ensemble play different melodies simultaneously, or when they play the same melody out of phase with each other, as in a fugue or canon. The difference between this combination and the second one above is only in the emphasis given to harmonic or contrapuntal structure. Fourth, a melody may be heard in isolation and yet *imply* a chord or a sequence of chords. This condition is the most intriguing, because it presupposes cognitive structures capable of abstracting an underlying harmony from a melody.

A melody usually consists of several segments, each of which might be accompanied by a different chord. The melody as a whole would thus be accompanied by a sequence of chords. For convenience, by melody I will mean a segment of a melody that would not require a change of chords during its duration.

For any given melody, not just any chord will be perceived as a coherent accompaniment. Some chords will be perceived as closely related to the melody, and others as unrelated or discordant. I will refer to the former as chords that fit the melody or provide an accompaniment to the melody. A melody may be perceived as implying a chord regardless of whether it is actually accompanied by a chord. Most Western melodies are of this sort. Schenker (1935/1979) argued that the listener abstracts an underlying harmonic structure from a melody. From the psychological point of view, this means that there is a level of processing at which a melody is represented in terms of its "underlying" chords. These underlying chords are those that would best accompany the melody.

In the simplest case, if a melody contains only those tones that are the components of one particular chord, that chord will be perceived as an accompaniment to the melody. The melody literally *instantiates* the chord. The most obvious instances of chord instantiation in music are broken chords or arpeggios. The problem for the listener occurs when no one chord contains all the tones in a given segment of a melody. Indeed, most melodies are of this form. Yet in most cases an accompanist would have little difficulty deciding on the most appropriate chord. Whatever the chosen chord, there will be some tones that are not chord tones, and would, without anchoring, clash or interfere with the tonal schema.

Several factors contribute to the implication of a chord by a melody. Chord tones tend to occur in metrically stressed positions more often than nonchord tones. Metrical stress thus provides a cue for the assignment of a chord to a melodic fragment. One of Lerdahl and Jackendoff's (1983) preference rules (which decide which tones in the surface string are to be carried over to a deeper level of representation) states that a tone with high metrical stress is preferred over one with low metrical stress. Yet one can imagine a piece in which metrical stress cannot account for the implication of a chord. Thus, Lerdahl and Jackendoff list several preference rules that come into play and occasionally even conflict with each other. This ambiguity is common. As Lerdahl and Jackendoff point out, it is a tool with which the composer may work. Although ambiguity is to be avoided in most uses of language, where truth value may be essential to meaning, this is not the case with music.

In the absence of metrical stress as a reliable cue, the activated tonal schema must be called upon to decide which tones in the melodic segment are to be treated as chord tones and which as nonchord tones. But this process may not be available at the beginning of a piece or at a transition point. The tonal schema must itself be activated by information obtainable from the musical stimulus. An obvious first candidate as a principle that would bring this about is a democratic rule of the majority: the greater the total number (or duration) of tones in a melody that are component tones of a particular chord, the more strongly that chord is implied. And if two chords have equal numbers of votes on this count, then a chord with all its component tones present in the melody is chosen over one with only some of its component tones present, and so on. However, even this may not decide the sequence B–C–D#–E–F#–G, in which two unrelated chords, B major and C major are equally represented. Even though both chords are members of the key of E minor, this sequence seems to imply C major. Deutsch and Feroe (1981) have developed a formal system designed to represent the tones in a melody in their hierarchy of stability. For the above sequence, this system shows C, E, and G as the most stable tones with B subordinate to C, D# subordinate to E, and F# subordinate to G. The tree structures used by Lerdahl and Jackendoff (1983) would also represent this hierarchical structure. What is needed is a rule to get us from the sequence to its hierarchical representation. This rule must make reference to the ordered relations between the tones in the sequence.

The principle of melodic anchoring specifies the ordered relations that would result in the implication of one chord over another in the absence of other cues. This is not to say that it is a principle of last resort. The traditional use of nonchord tones in highly constrained ways (see Piston, 1962; Schenker, 1935/1979; Schoenberg, 1954/1969) and with considerable frequency (particularly since the rise in the use of chromaticism) suggests that melodic anchoring plays an important role in the ongoing processing of tonal music in general.

Probably the most commonly used nonchord tones are the passing tone, the auxiliary tone, and the appoggiatura (see Piston, 1962). In the sequence C–D–E, D is a passing tone. It smooths out the leap from one chord tone to the next, and is generally on a weak metrical beat. An auxiliary tone is like the passing tone except that the same chord tone precedes and follows it, e.g., D in C–D–C. The appoggiatura is a nonchord tone whose dissonance is emphasized by being placed on a strong metrical beat. It is described as having the quality of "leaning" on the beat before resolving to the chord tone that follows it. This taxonomy of nonchord tones is useful stylistically but does not illuminate their psychological representation. One feature seems to be common to the standard use of nonchord tones: they are followed by chord tones that are neighbors in the diatonic or chromatic scale, thus fulfilling the two constraints on melodic anchoring.

MELODIC ANCHORING

Melodic anchoring is constrained in two ways. First, the stable anchor must follow the unstable tone in temporal sequence. This reflects the asymmetric property of the relationship between tones differing in stability (Krumhansl, 1979). Anchoring thus occurs only forward in time. This constraint will be referred to as the *asymmetry constraint,* because it concerns the ordered relationships between tones. For example, the ascending sequence G–B–C–E is easily accompanied by a C major chord (whose component tones are C, E, and G); the B does not interfere with the chord, since it is anchored by the C following it. If the B and C are reversed as in G–C–B–E, the B interferes with the C major chord and therefore calls for a change of chord to E minor, of which both B and the following E are component tones.

Second, the unstable tone and its anchor must be pitch neighbors (along an entrenched musical scale). Not just any stable tone will serve as an adequate anchor for a given unstable tone. Proximity along the dimension of pitch brings with it some processing efficiency (see Deutsch, 1978) and permits the listener to perceive the unstable tone not in isolation but as related to its stable neighbor. This will be referred to as the *pitch proximity constraint.* For example, while parsing a melody into segments corresponding to its underlying chord functions, the segment G–E–B–C is easily accompanied by a C major chord because the B is anchored to the C following it. If the B is replaced by an F as in G–E–F–C, the F interferes with the C major chord and calls for a change of chord to F major, of which both F and the following C are component tones. B and C are pitch neighbors but F and C are not.

The principle of melodic anchoring, as applied to Western harmonically based hierarchies of stability, specifically states that a melody will not interfere with a given chord to the extent that each tone satisfies one of the following three conditions.

a. Chord Instantiation

A tone satisfies *chord instantiation* if it is a chord tone. A chord tone contributes to, does not interfere with, the tonal schema by virtue of being stable. This condition is trivially true and involves no anchoring.

b Immediate Anchoring

A tone satisfies *immediate anchoring* if it is a nonchord tone and is followed immediately by a chord tone that is a neighbor in either the diatonic or chromatic scale. The top of Fig. 2 shows D followed by E. With respect to the C major chord, E is a chord tone but D is not. D and E are neighbors in the C major scale (see Fig. 1). In this example, the nonchord tone is diatonic, i.e., it is a member of the C major scale. Strictly speaking, the fact that C major is the chord in question does not mean that C major is the scale in which the neighborhood relation must hold. The chord currently accompanying a melody may be C major but the overall key of the piece need not be C major. The neighborhood relation must hold in the diatonic scale of the key. In the examples in Fig. 2, the chord in question is assumed to be the tonic chord of the key, for convenience.

The bottom of Fig. 2 shows an example of a nonchord tone that is nondiatonic, i.e., not from the diatonic scale. The nonchord tone and its anchor are not neighbors in the diatonic scale, but are neighbors in the chromatic scale (see Fig. 1).

c. Delayed Anchoring

Nonchord tones are occasionally not resolved immediately. The example at the top of Fig. 3 is not uncommon in music. Here, the anchoring of D is delayed by the interpolation of another tone, F, which is itself anchored immediately. The original unstable tone and the interpolated unstable tone are each anchored independently by adhering to the pitch

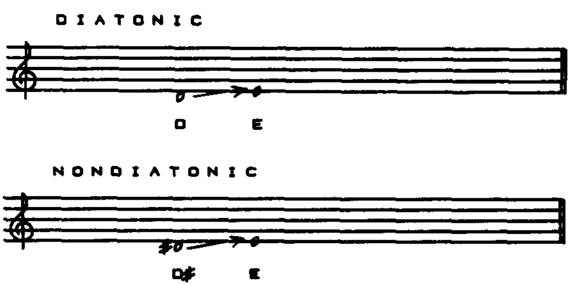

FIG. 2. Immediate anchoring. In the context of a C major chord, E is a chord tone (hence stable). Nonchord tones such as D (diatonic) or D# (nondiatonic) are unstable but can be anchored to E immediately since E follows immediately and is a pitch neighbor.

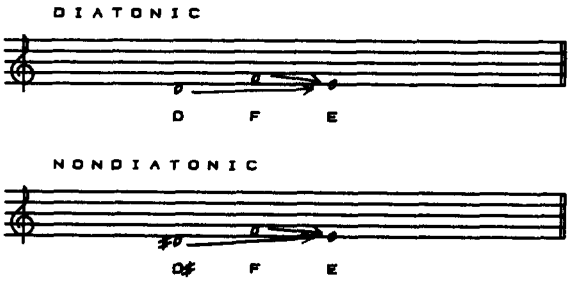

FIG. 3. Delayed anchoring. In the context of a C major chord, E is a chord tone (hence stable). Nonchord tones such as D (diatonic) or D# (nondiatonic) can be anchored to E in a delayed fashion since the interpolated tone (F) is itself anchored immediately.

proximity constraint. A delayed anchoring usually has an immediate anchoring nested within it. The bottom of Fig. 3 shows delayed anchoring of a nondiatonic tone.

A tone satisfies *delayed anchoring* if it is a nonchord tone that is followed by another nonchord tone that satisfies immediate anchoring, and if it would satisfy immediate anchoring in the absence of the interpolated tone.

A nonchord tone could perhaps serve as an anchor provided it is itself anchored. Take, for example, the sequence B^b–B–C. B is anchored to C. Since anchoring serves to increase the stability of an otherwise unstable tone, B can serve as an anchor for B^b. These cases tend to occur in quick passages in which the short durations of the unstable tones minimize the interfering effect. They will not be tested in the following series of experiments.

Anchoring can occur in two pitch directions. When the anchor is higher in pitch than the anchored tone, the anchoring will be referred to as ascending; when the anchor is lower in pitch, the anchoring will be referred to as descending.

OVERVIEW OF EXPERIMENTS

The first three experiments were designed to test immediate anchoring, and the last three delayed anchoring. In the first and fourth experiments, the subject's task was to choose one of several alternative chords as the best potential accompaniment to an ambiguous melody; these choices were compared with choices predicted by melodic anchoring. The second and fifth experiments used a recognition memory paradigm in which melodic anchoring predicts a specific pattern of short-term memory confusions. In the third and sixth experiments, subjects rated how well particular chords sounded with particular melodies.

EXPERIMENT 1

Subjects were presented with a melody that would be ambiguous were it not for the ordered relationships between its tones. Each melody contained the three component tones of each of two different chords, in this case B major and C major (see Fig. 4). The tones were interleaved so that with respect to one chord, the first, third, and fifth tones were chord tones and the others were nonchord tones; with respect to the other chord, the second, fourth, and sixth tones were chord tones and the others were nonchord tones. In one block of trials, subjects heard a six-tone melody followed by a chord and then the same melody followed by another chord. In another block of trials, subjects heard a chord first followed by the melody, then another chord followed by the same melody. Subjects were instructed to choose the chord that fit the melody best. Each melody was constructed so that the three tones of one chord were anchored to the three tones of the other. It was predicted that subjects would choose the chord that gives the best fit to the melody according to the principle of melodic anchoring.

Each of the components of the B major chord was paired with the corresponding component of the C major chord. B was always paired with C, D# with E, and F# with G. Each melody contained each of these three pairs (the pairs themselves being in any order), such that the first tones of all pairs were either (i) the component tones of B major, in which case the pairs would be B–C, D#–E, and F#–G (as in the middle of Fig. 4), or (ii) the component tones of C major, in which case the pairs would

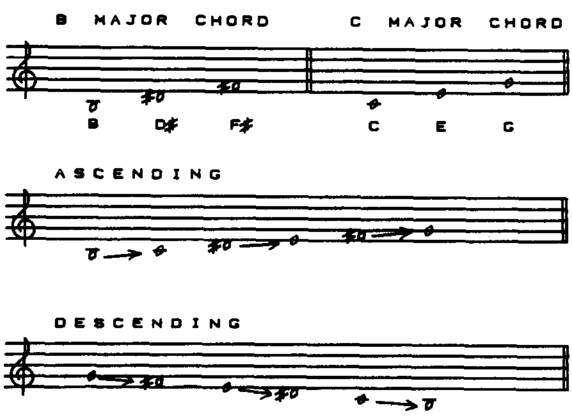

FIG. 4. Ambiguous melody. The component tones of the B major chord and the C major chord (top). The components of B are anchored by the components of C (middle). The components of C are anchored by the components of B (bottom) (Bharucha, 1984; copyright © 1984 by the American Psychological Association, reprinted by permission).

be C–B, E–D#, and G–F# (as in the bottom of Fig. 4). The first tone of each pair was anchored by the second. In Fig. 4, case (ii) is represented as the retrograde of case (i).

Consider how the principle of melodic anchoring decides between B major or C major as the chord that best fits. If the pairs are ascending (B–C, D#–E, F#–G) as in the middle of Fig. 4, the better fitting chord would be C major. This is because C, E, and G would satisfy chord instantiation, and B, D#, and F# would satisfy immediate anchoring. An attempt to fit the B major chord results in B, D#, and F# being satisfied by chord instantiation but C, E, and G not being satisfied at all. If instead the melody is reversed so that the pairs are descending (as in the bottom of Fig. 4), the better fitting chord would be B major. B, D#, and F# satisfy chord instantiation, and C, E, and G satisfy immediate anchoring. An attempt to fit B major fails to accommodate the tones from C major. Inherent in the design is an advantage for the B major chord over the C major chord because the only key of which both are members is E minor, in which B is the dominant and hence more stable than C. For the descending sequences, a strong observed preference for B over C (as predicted) would not be conclusive evidence for melodic anchoring because of this confounding factor. For the ascending sequences, however, the two factors are in conflict, and an observed preference for C over B (as predicted) would be strong evidence for melodic anchoring.

Method

Subjects. Eighteen subjects from the Cornell summer community were paid $2.50 for participating in one 45-min session. Half the subjects reported having received no musical instruction and half reported at least 3 years of instruction. Subjects in the latter group reported an average of 7.9 years of musical instruction, currently played a musical instrument or sang for an average of 3.2 h per week, but reported never having taken a course in music theory. All subjects reported normal hearing, and none reported having absolute pitch.

Apparatus. A Hewlett–Packard 1000L computer was programmed to generate tones and chords by creating digital representations and playing them out through a digital-to-analog converter (Hewlett–Packard 59303A). A frequency filter (A.P. Circuit Corp. AP-255-5) was used to eliminate noise introduced by the conversion process. The stimuli were presented on-line through an Ampex AA-620 loudspeaker at approximately 67 dBA sound pressure level. A Hewlett–Packard (2621A) terminal was used to record subjects' responses.

Stimuli. Tones were constructed by sampling the same pitch class over a five-octave range, imposing an amplitude envelope over the frequency domain such that component tones at the low and high ends of the range tapered off to loudness threshold. Tones of this sort are ambiguous as to the particular octave they are in (Shepard, 1964), thus controlling for effects due to pitch height alone. Chords were constructed by sampling the three component tones over the same five-octave range and imposing the same amplitude envelope. Chords of this sort are ambiguous as to their bass note, thus controlling for differences in the inversion of the chord (Krumhansl, Bharucha, & Kessler, 1982). Each tone lasted 200 ms, with 10-ms amplitude rise and fall times. A 50-ms interval separated tones within a melody. Each chord lasted 300 ms.

Each trial began with a double presentation of a melody, without a pause between the two presentations. Following a 1.5-s interval, two melody-chord pairs were presented. The interval between the initial double presentation and the first melody-chord pair was 1.5 s, as was the interval between the two melody-chord pairs. The melody and chord within a pair were separated by 750 ms. The melody in both melody-chord pairs was the same as the melody in the initial double presentation. The chords in the two melody-chord pairs were always different.

There were two blocks of trials. Chords were presented after their paired melodies in one block (chord-after condition), and before them in the other (chord-before condition). Twenty-four different melodies were used. Each melody occurred in two different trials per block, once for each presentation order of the two melody-chord pairs. Melodies were randomized within a block, and were randomly transposed to begin on any one of the 12 chromatic tones.

Melodies were constructed in the following manner. Each melody consisted of the three tones of the B major chord (B, D#, F#) and the three tones of the C major chord (C, E, G), such that either all three ascending ordered pairs (B–C, D#–E, F#–G) or all three descending ordered pairs (C–B, E–D#, G–F#) were present. Thus, serial positions 1, 3, and 5 contained the tones from one chord and serial positions 2, 4, and 6 contained the tones from the other. There are six different permutations of the three ascending pairs and six of the three descending pairs, one set consisting of the mirror images or "retrogrades" of the other. These 12 melodies were then the basis for constructing 12 other melodies shifted out of phase by removing the last tone and inserting it before the first. These phase-shifted melodies were designed to control for biasing the chord selection in favor of the last tone in the chord-after trials or in favor of the first tone in the chord-before trials. The only drawback of these phase-shifted transformations was that the last tone of each melody was left dangling without being anchored. This was partially overcome by presenting the melody twice in succession at the beginning of each trial, so that the last tone of the first presentation was anchored by the first tone of the second presentation.

Procedure. On each trial, subjects heard a six-tone melody played twice in succession, followed by the same melody preceded or followed first by one chord and then by another. Subjects indicated which of the two chords they judged to be a better fit to the melody, and how confident they were of this choice. The following response scale was used: 1 = first chord, confident; 2 = first chord, not so confident; 3 = second chord, confident; 4 = second chord, not so confident. Subjects entered their responses on the keyboard of a computer terminal.

Results

The expected probability of choosing one chord over the other by chance is .5. The observed mean probability of choosing the predicted chord over the alternative was .583, significantly greater than chance ($t(17) = 3.09$, $p < .01$). Areas under Receiver Operating Characteristic (ROC) curves were computed with the three response criteria provided by subjects' confidence ratings (Green & Swets, 1966) to control for selective bias. For this purpose, choosing the predicted chord was scored as a hit, and choosing the alternative chord was scored as a false alarm. The overall mean area under the ROC curve was .581, which was significantly greater than chance ($t(17) = 2.86$, $p < .05$).

TABLE 1
Choice Probabilities for Experiment 1

	Ascending	Descending	Mean
Moderately trained subjects	.581*	.744**	.663**
Untrained subjects	.463	.542	.503
Mean	.523	.643**	.583**

* $p < .05$.
** $p < .01$.

Probability values for the two subject groups and for ascending and descending melodies are shown in Table 1. Subjects who reported having received moderate musical training showed a strong preference for the predicted chord (.663), whereas subjects with no musical training did not (.503). There was in general a greater preference for the predicted chord in melodies with descending anchoring than in melodies with ascending anchoring ($F(1,17) = 9.74$, $p < .01$). However, even for the melodies with ascending anchoring, the trained subjects showed a preference (.581) significantly greater than chance ($t(8) = 1.90$, $p < .05$).

Discussion

Subjects with moderate musical training showed a significant preference for the chord predicted by the principle of melodic anchoring. None of the subjects in this group had taken a course in music theory, and were thus probably not explicitly aware of the theoretical guidelines for using nonchord tones. Of the two alternative chords whose component tones were represented in the ambiguous melody, these subjects chose the chord with respect to which each tone in the melody could be processed as either a chord tone or an anchored nonchord tone. The preference for the predicted chord over the alternative was stronger for descending anchoring pairs than for ascending anchoring pairs. This is because all six tones are members of the key of E minor. Insofar as this key is activated, B major (the dominant) is more strongly suggested than C major (the chord based on the sixth scale degree). For the descending sequences, the ordered relationships are such that the anchoring principle also predicts that B major will be the stronger chord. For the ascending sequences, however, the anchoring principle makes the opposite prediction. The observed preference for C major over B major in spite of the advantage in favor of B major demonstrates that subjects' decisions were sensitive to the ordered relationships of the tones, since no other cues were available that could explain this response.

The preference for the predicted chord was not as strong as expected (.663 for the moderately trained subjects and no preference for the untrained subjects). Either the untrained listeners were not sensitive to the ordered relations of tones as specified by melodic anchoring or the task was unable to tap their intuitions. Bharucha & Krumhansl (1983) found that the responses of novices show more structure in memory tasks than in subjective rating tasks. The next experiment employed a recognition memory paradigm in the hope that a task in which there is a right and a wrong answer may be more sensitive than one employing a subjective choice. The staccato caused by 50-ms pauses between tones may also have contributed to the weak preference; subjects mentioned that the melodies sounded artificially disjunct. This was unavoidable, since the computer had to read a file containing the entire digital representation of a Shepard tone before playing it. Evidence of anchoring effects in the next experiment would also rule out possible task demand accounts of a subjective rating design, and provide convergent evidence for a robust cognitive process.

EXPERIMENT 2

Melodic anchoring states the conditions under which the stability of a nonchord tone (unstable) can be effectively increased by assimilating it to the tonal schema. In this experiment, a same–different task, subjects heard two melodies in succession. The melodies were either identical or the tone in one serial position (the target position) was altered. Melodic anchoring predicts that if the tone in the target position is changed from a chord tone to a nonchord tone, the two melodies would be more confusable if the nonchord tone is anchored than if it is not.

Memory processes are sensitive to the differentiation of musical elements on the basis of stability (Bharucha & Krumhansl, 1983; Cuddy, Cohen, & Miller, 1979; Dowling, 1978; Francès, 1972; Krumhansl, 1979; Krumhansl, Bharucha, & Castellano, 1982). Francès (1972) claimed that it is easier to detect an alteration to a tonal melody than to an atonal melody. However, this depends upon whether the alteration conforms to or violates the tonal schema. Alterations to a tonal sequence are easily confused with the original if they can be assimilated to the prevailing tonal schema. This is true for sequences of tones (e.g., Dowling, 1978) as well as for sequences of chords (Bharucha & Krumhansl, 1983). The activation of a tonal schema involves the drawing together—in psychological space—of stable tones. Tones that are closer together in psychological space are thus more easily confused with each other. Alterations that violate the tonal schema are easily detected (Bharucha & Krumhansl, 1983). Thus, if anchoring serves to assimilate an unstable tone to the tonal schema, inserting a nonchord tone into a tonal sequence should be more difficult to detect if it is anchored than if it is not.

A second prediction concerns memory confusions as a function of the presentation order of the two sequences. Bharucha and Krumhansl (1983) found that alterations to a chord sequence that violate the tonal schema of the original are easier to detect if the original is played first and the alteration second than if they are played in the reverse order. Bartlett (1984) reports similar data for tones. In the present experiment, fewer confusions should occur when the target position contains a chord tone in the first sequence and a nonchord tone in the second sequence than vice versa. The prediction for anchoring is that this asymmetry (the difference between confusion rates for the two presentation orders) should be smaller when the nonchord tone is anchored than when it is not. The rationale behind this prediction is as follows. The expected asymmetry is due to the difference in stability between the tones in the target positions of the two sequences. If anchoring permits a nonchord tone to be assimilated, it effectively increases its stability, thereby reducing its difference in stability relative to the chord tone target in the other sequence.

The sequence of three tones at the top left of Fig. 5 consists of the tones E, G, and C. These three tones instantiate a C major chord. If G (the middle tone) is replaced by a B to form the melody labeled "Anchoring," B would be anchored by the C that follows it, because B and C are pitch neighbors in the C major scale. Even though B is a nonchord tone with respect to the C major chord (whose components are C, E, and G), melodic anchoring would predict that C major is still the chord that fits this melody; E and C are chord tones, which directly instantiate the C major chord, and B is a nonchord tone that is anchored by C.

If, instead, G is replaced by F, as in the botton of Fig. 5, the resulting melody would not fit the C major chord, because F is not anchored. The pitch distance between F and the C following it is too great, according to melodic anchoring, to permit the F to be easily assimilated. In Fig. 5, whether G is replaced by B or by F, the contour (the pattern of ups and

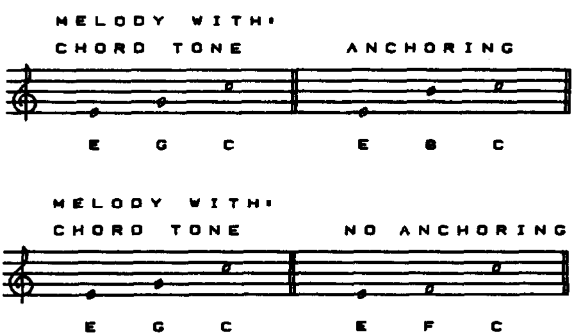

FIG. 5. Design of memory experiment for immediate anchoring (Experiment 2). One tone (G) of a sequence of chord tones (E–G–C) is replaced by a nonchord tone that is either anchored (top) or not anchored (bottom).

downs) remains constant. The total pitch distance traversed from the first tone to the last also remains constant; if the pitch distance from the first tone to the second is increased (top of Fig. 5), the distance from the second tone to the third is decreased correspondingly, and vice versa (bottom of Fig. 5). This design controls for recognition cues due to alterations of pitch contour or of pitch height.

In the present experiment, three-tone sequences such as those in Fig. 5 were embedded within five-tone melodies. For example, the sequence E–G–C (top and bottom left) was part of the melody E–G–C–D–E; the sequence E–B–C (top right) was part of the melody E–B–C–D–E, and the sequence E–F–C (bottom right) was part of the melody E–F–C–D–E. These melodies differ in terms of only one tone. Melodic anchoring predicts that the top two melodies are more likely to be confused with each other than the bottom two, in a same-different recognition memory task. This is because anchoring increases the stability of nonchord tones relative to chord tones, and the experiments cited above suggest that tones less differentiated on the basis of stability are more likely to be confused with each other in short-term memory. In both examples, more confusion errors are expected when the sequence containing the nonchord tone occurs first. However, this difference is predicted to be greater for the bottom of Fig. 5 than for the top.

Method

Subjects. Fourteen Cornell students were paid $2 for participating in one 40-min session. Subjects were recruited in two groups: one group having had no musical instruction at all (untrained group) and the other having received musical instruction for at least 3 years (moderately trained group). Subjects in the moderately trained group reported an average of 7.5 years of instruction on a musical instrument. All subjects reported having normal hearing, and none reported having absolute pitch.

Apparatus. The tones were generated digitally by a DMX-1000 signal processing computer under the control of a PDP-11/24 computer. The DMX-1000 performs the digital synthesis in real time, generates the signal through a 16-bit digital-to-analog converter, and filters the signal at the Nyquist frequency. The stimuli were presented to subjects on-line in an audiometric chamber through a speaker at approximately 63 dBA sound pressure level.

Stimuli. Tones were selected from the range of C4 to G5 (261.6 to 784.0 Hz) using an equal tempered tuning based on 440 Hz. Each tone consisted of the fundamental frequency plus the first five harmonics above the fundamental; each upper harmonic was one third the amplitude of the fundamental. Each tone lasted 200 ms with 20-ms rise and fall times. The interval between the standard and comparison melodies was 600 ms. There was no pause between tones of a melody.

On each trial, subjects heard a sequence of five tones (the standard melody) followed by another sequence of five tones (the comparison melody). On half the trials (the "same" trials) the standard and comparison melodies were identical. On the other half (the "different" trials), one tone was changed from a chord tone to a nonchord tone or vice versa. The nonchord tone will be called the target. The change occurred in either the second or the fourth serial position (the target position). The tones before and after the target position were always chord tones. The target was either anchored or not. For every trial in which the target occurred in the comparison melody, there was a corresponding trial in which the presentation order was reversed so that the target occurred in the standard melody. All melodies used as standard or comparison sequences on "different" trials were also used on "same" trials. The target was either diatonic or nondiatonic, and the anchoring was either in the ascending or descending direction.

The tone in the target position was always intermediate in pitch with respect to the two chord tones flanking it. This held the total pitch distance traversed constant while the tone in the target position changed. Care was taken to rule out tone progressions that would instantiate some chord other than C, to ensure that the target was indeed being perceived as a nonchord tone and not simply as a chord tone of another chord. The tones in the target positions of the standard and the comparison never occurred in any other position in the melody.

Procedure. Subjects were run individually or in pairs. For each trial, subjects indicated whether the standard and comparison melodies were the same or different and how confident they were of this judgment. The following response scale was used: -2 = same, confident; -1 = same, not so confident; 1 = different, not so confident; 2 = different, confident. Responses were recorded by circling the appropriate number on a response sheet. Subjects had 3.8 s to respond before the next trial began. The end of each group of 10 trials was signaled by a click for subjects to make sure they were at the correct trial number on their response sheet. There were 256 trials in all, presented in random order divided into two sets that lasted 14 min each. Subjects were given 10 practice trials before the experiment.

Results

Probability-correct scores were computed for the "same" and "different" trials separately. There was a strong overall tendency for subjects to respond "same"; the average probability correct was .882 and .571 for "same" and "different" trials, respectively. Subjects' confidence ratings were used to compute areas under Receiver Operating Characteristic (ROC) curves (Green & Swets, 1966) to dissociate effects of differential bias from effects of differential sensitivity.

Anchoring. For the "different" trials, performance was worse (more confusions occurred) when targets were anchored (.488) than when they were not anchored (.654) ($F(1,12) = 32.96$, $p < .0001$). Thus, a nonchord tone is more easily confused with a chord tone if it is anchored than if it is not. This is confirmation of melodic anchoring as a principle influencing short-term memory for melodies.

For the "same" trials, melodies were correctly recognized more often if they did not contain a nonchord tone than if they did ($F(1,12) = 16.62$, $p < .002$); a nonchord tone was more likely to be correctly recognized when it was anchored (.916) than when it was not (.848) ($F(1,12) = 14.14$, $p < .003$). This provides additional support for melodic anchoring: anchoring causes an unstable tone to behave more like a stable tone than it otherwise would.

For both "different" as well as "same" trials, subjects were more likely to respond "same" when the target was anchored than when it was not. However, the analysis of ROC curves showed significantly more confusions when the target was anchored (.746) than when it was not (.772) ($F(1,12) = 8.31$, $p < .02$). Subjects were therefore less sensitive to the difference between a chord tone and a nonchord tone when the nonchord tone was anchored than when it was not, as predicted.

The following analyses use only the probability-correct data for "different" trials. The effects of interest were also born out using ROC data.

Musical training. Untrained subjects showed the same pattern of responses as moderately trained subjects, although the latter performed at significantly higher overall levels ($F(1,12) = 5.64$, $p < .05$). There were no interactions between level of training and any of the other factors.

Presentation order. More confusions occurred when the target was in the standard melody (.440) than when it was in the comparison melody (.702) ($F(1,12) = 54.12$, $p < .0001$), as expected. This effect of presentation order was weaker when the target was anchored than when it was not ($F(1,12) = 20.95$, $p < .0001$), as predicted (see Fig. 6). An equivalent description of this interaction is that the anchoring effect (the difference in height between "Anchoring" and "No Anchoring" bars in Fig. 6) is weaker when the nonchord tone is in the standard melody.

Diatonic vs nondiatonic targets. More confusions occurred, on the average, when the nonchord tone was diatonic (.518) than when it was nondiatonic (.624) ($F(1,12) = 45.81$, $p < .0001$). This is a consequence of the greater stability of diatonic tones as compared to nondiatonic tones, all other things being equal. However, an interesting interaction in favor of the anchoring hypothesis emerges when examining the data for the presentation order in which the target occurs in the comparison melody.

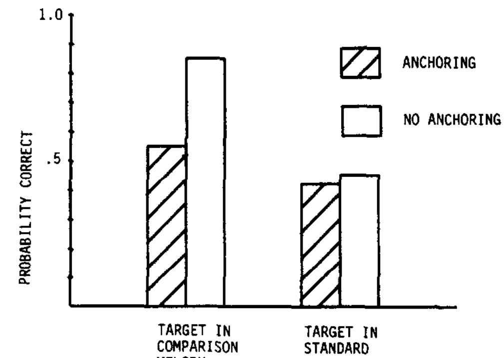

FIG. 6. An effect of immediate anchoring is indicated by the "Anchoring" bar being shorter than the "No Anchoring" bar. More confusions occur when a chord tone is replaced by a nonchord tone that is anchored than by one that is not. An anchoring effect is more pronounced when the nonchord tone (target) is in the comparison melody.

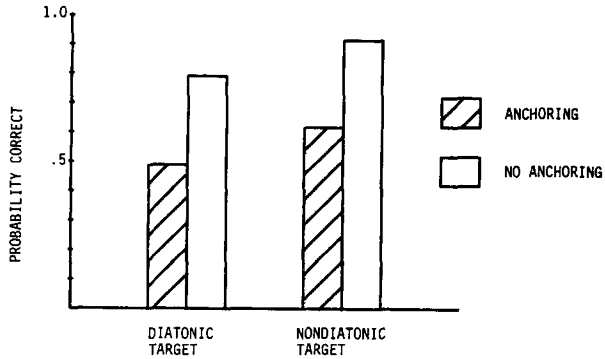

FIG. 7. An effect of immediate anchoring is seen for both diatonic and nondiatonic nonchord tones. Furthermore, more confusions occur when a chord tone is replaced by a nondiatonic tone that is anchored than by a diatonic tone that is not anchored.

Although anchoring effects are evident for both diatonic and nondiatonic targets (see Fig. 7), the nondiatonic anchoring bar is lower than the diatonic no-anchoring bar ($t(13) = 3.40$, $p < .005$). More confusions occurred when the target was nondiatonic and anchored than when it was diatonic but not anchored. All things being equal, nondiatonic tones are more unstable than diatonic tones. However, anchoring renders nondiatonic tones more stable than diatonic tones that are not anchored.

Discussion

This experiment demonstrates that melodic anchoring is a robust principle of melodic organization, even for musically untrained listeners. A nonchord tone was more easily confused with a chord tone when it was anchored than when it was not. Nonchord tones are thus less conspicuous when they are anchored than when they are not. Anchoring has the effect of raising the stability of an otherwise unstable tone.

Subjects who reporting having received no musical training showed the same pattern of responses as subjects with moderate musical training. It is possible that a memory task (such as the present one) is more suited to revealing the musical intuitions of the novice than a task involving subjective preferences (as in the previous experiment). We can conclude that even musical novices use the temporal ordering of tones (as specified by melodic anchoring) to establish their relative stability.

Support for the principle also comes from the effect of presentation order. More confusions occurred when the nonchord tone was in the standard melody than when it was in the comparison melody. The lesson: if you are performing a piece unfamiliar to the audience, your wrong notes are less exposed in the first statement of the theme than in subsequent statements. This parallels results reported by Bartlett (1984) for melodies and by Bharucha and Krumhansl (1983) for chord sequences. The present study found that this effect of presentation order is reduced when the nonchord tone is anchored. If you anchor your wrong notes, it is not as important that you play them in the first statement of the theme rather than in subsequent statements.

The most interesting result in support of melodic anchoring was the difference between nondiatonic tones that were anchored and diatonic tones that were not anchored. Diatonic tones are generally considered more stable than nondiatonic tones. However, a nonchord tone that is nondiatonic but anchored is more stable than one that is diatonic but not anchored. Anchoring is capable of rendering nondiatonic tones more stable than diatonic tones.

EXPERIMENT 3

The melodies used in the first two experiments were thought to imply chords but were never explicitly accompanied by them. Subjects abstracted an underlying chord from the melody, in line with Schenker's (1935/1979) theory. The explicit sounding of a chord was avoided to test the view that harmonic considerations are decisive even for melodies heard alone. This has been borne out, even for the musically untrained.

The present experiment was designed to see if the melodies used in the memory experiment would, when accompanied by a chord, elicit rating judgments that mirrored the memory judgments. On each trial, subjects heard a melody and a chord played simultaneously, and were required to rate how well the chord accompanied the melody. The principle of melodic anchoring states that a nonchord tone will interfere with the underlying chord unless it is anchored. It was predicted that melodies with nonchord tones that were anchored would be given higher ratings than melodies with nonchord tones that were not anchored.

Method

Subjects. Fifteen Cornell students were paid $2 for participating in one 30-min session. Subjects were recruited regardless of musical background. Seven of the subjects reported having received no musical instruction at all. Five reported between 1 and 3 (an average of 2.2) years of instruction, mostly in elementary or junior high school. The remaining three reported between 8 and 16 (an average of 12) years of instruction. All subjects reported having normal hearing and none reported absolute pitch.

Apparatus. The apparatus was the same as in Experiment 2. The stimuli were presented to most of the subjects on-line from the computer, but were presented via prerecorded tapes (Scotch 208) on a tape recorder (Sony TC-388-4) to some subjects.

Stimuli. On each trial subjects heard a sequence of five tones with a chord sounding simultaneously. The melodies were exactly the same as in Experiment 2, but were accompanied by a chord. The chord consisted of C, E, and G in the octave below the melody, and sounded continuously for the duration of the melody.

One third of the trials contained melodies with nonchord tones that were anchored. One third contained melodies that were the same in all respects except that the nonchord tones were not anchored. The remaining one third of the trials contained the same melodies with chord tones in the place of the nonchord tones. Half the nonchord tones were diatonic and half were nondiatonic.

Procedure. The task was to rate, on a scale from 1 to 5, how well the melody and the chord sounded together, or how musical the melody sounded in the presence of the chord. Subjects responded by circling a number from 1 to 5 on a response sheet. Subjects had 3.8 s in which to respond before the next trial began. The end of each group of 10 trials was signaled by a click for subjects to make sure they were at the correct trial number on their response sheet.

Subjects were given 10 practice trials before the experiment. There were 192 trials in all, presented in random order, divided into two sets lasting 10 min each.

Results

The raw scores of the two replications in this experiment were correlated for each subject. Thirteen of the fifteen subjects gave ratings that correlated significantly ($\alpha = .05$) across replications. The ratings of the remaining two subjects did not correlate significantly across replications (their correlation coefficients were .19 and −.12). These two subjects were omitted from the following analysis. The chord tone melodies received the highest ratings (3.55), followed by melodies with anchoring (2.84) and then melodies with no anchoring (2.60). Melodies with anchoring received significantly higher ratings than melodies with no anchoring ($t(12) = 2.17$, $p < .05$). This demonstrates that immediate anchoring is reflected in rating judgments as well. When a melody contains a nonchord tone (with respect to a given chord), the melody is heard as being better accompanied by that chord if the nonchord tone is anchored than if it is not.

Diatonic melodies were given higher ratings (3.12) than melodies that contained a nondiatonic tone (2.31), ($F(1,12) = 31.61$, $p < .0005$). Nondiatonic tones interfere with the chord more than diatonic tones. Unlike the results of the memory experiment, however, melodies with nondiatonic tones that were anchored were not given higher ratings than melodies with diatonic tones that were not anchored.

Discussion

The rating judgments in the present experiment generally converge on the memory data for the same melodies. When a melody contained a nonchord tone, the accompanying chord was judged to be a better accompaniment when the nonchord tone was anchored than when it was not. Nonchord tones that were not anchored were therefore perceived as interfering with the accompanying chord, as predicted by melodic anchoring. The convergence of rating and memory judgments points to the robustness of the anchoring principle. Unlike the memory judgments, however, the rating judgments did not show anchored nondiatonic tones to be more stable than diatonic tones that were not anchored.

In the first three experiments, anchoring was always immediate. The anchored nonchord tones always satisfied the immediate anchoring condition of the principle of melodic anchoring. The next three experiments test the delayed anchoring condition using the same tasks as the first three experiments.

EXPERIMENT 4

This experiment was similar to Experiment 1, except that three more tones were introduced to test the delayed anchoring condition. Each melody contained the three component tones of each of three different chords. The melody was thus ambiguous with respect to three different chords if the ordered relationships of the tones were not important, since all three chords were represented equally in the melody. Melodic anchoring predicts that one chord will be heard as a better accompaniment of the melody than the other two.

Each melody contained nine tones, three of which were the component tones of the B major chord, three of which were the component tones of the C major chord, and three of which were the component tones of the D^b major chord. This is shown in Fig. 8. Each melody contained three ordered triples, each triple containing corresponding components of each of the three chords. The ordering of tones within the triples was always as follows: D^b–B–C, F–D#–E, and A^b–F#–G. Of the three chords (B, C, and D^b major), C major is the only one that obtains a fit to the principle of melodic anchoring. If C, E, and G satisfy chord instantiation then B, D#, and F# will satisfy immediate anchoring, and D^b, F, and A^b will satisfy delayed anchoring. The components of B major are anchored immediately, in the ascending direction. The components of D^b major are anchored in a delayed fashion, in the descending direction. The reverse

FIG. 8. Doubly ambiguous melody. The component tones of the B major chord, the C major chord, and the D^b major chord (top). The components of C anchor the components of D^b in a delayed fashion and anchor the components of B immediately (bottom).

case (immediate descending and delayed ascending) was not included in the experiment.

Let $p(i;j)$ be the probability of choosing chord i over chord j. It was predicted that $p(C;B)$ would be greater than chance, and that $p(C;D^b)$ would be greater than chance.

Method

Subjects. Twenty subjects from the Cornell summer community were paid $2.50 for participating in one 45-min session. Half the subjects reported having received no musical instruction. The other half reported at least 3 years of musical instruction (averaging 8.2 years), currently played a musical instrument or sang for an average of 2.9 h per week, but reported never having taken a course in music theory. All subjects reported normal hearing, and none reported absolute pitch.

Apparatus and stimuli. The apparatus and acoustical specifications of the stimuli were the same as in Experiment 1. Each trial began with a double presentation of a melody, without a pause between the two presentations. Subjects then heard one melody-chord pair followed by another melody-chord pair. There were two blocks of trials. Each chord was presented after its paired melody in one block and before it in the other. Melodies were randomized within a block, and were randomly transposed to begin on any one of the 12 chromatic tones. Each melody occurred in six different trials, one for each pairwise comparison of the three different chords. Melodies were constructed using the 3 component tones of each of the following chords: D^b major (D^b, F, A^b), B major (B, D#, F#), and C major (C, E, G). All six permutations of the following ordered triples were used: D^b–B–C, F–D#–E, and A^b–F#–G.

Procedure. On each trial, subjects heard a nine-tone melody played twice in succession, followed by the same melody preceded or followed first by one chord and then by another. Subjects indicated which of the two chords they judged to be a better fit to the melody, and how confident they were of this choice, as in Experiment 1.

Results

The overall probability that C major was selected over D^b major or over B major, i.e., the mean of $p(C;B)$ and $p(C;D^b)$ was .584. This is significantly greater than chance ($t(19) = 2.66, p < .01$). Computing areas under ROC curves (as described in Experiment 1), an even stronger effect (.600) was evident ($t(19) = 2.90, p < .005$). Thus, out of three chords equally represented in the melodies, subjects chose one over both the others, as predicted.

Subjects with moderate musical training showed a greater tendency to choose the hypothesized chord than untrained subjects. For moderately trained subjects, both $p(C;B)$ and $p(C;D^b)$ were significantly greater than chance ($t(9) = 2.39$ and $t(9) = 1.91, p < .05$, respectively). For the untrained subjects, only $p(C;D^b)$ was significantly greater than chance ($t(9) = 1.90, p < .05$). Thus, the untrained subjects showed a significant preference for C major over D^b major, but not for C major over B major.

In order to compare all three chords, the pairwise choice probabilities were used to locate each chord along a preference scale for each subject.

Using Luce's choice axiom (Baird & Noma, 1978; Luce, 1959), each probability $p(i;j)$ was converted into a distance z_{ij}, where

$$z_{ij} = -\ln \frac{1 - p(i;j)}{p(i;j)} .$$

The scale value for chord i was then found by averaging z_{ij} and z_{ik}. Figure 9 shows the mean scale values for B, C, and D^b. The scale value for C was the highest (.693), followed by B (−.078), and then by D^b (−.921). Thus, the immediate anchoring of the component tones of B major increased the stability of these tones with respect to the tones whose anchoring was delayed.

Discussion

Both immediate anchoring and delayed anchoring were supported by the subjects with moderate musical training, and delayed anchoring was supported by subjects with no musical training. Subjects' preference ranking of the three chords (see Fig. 9) was in the order predicted by melodic anchoring. The chord whose component tones served as anchors was ranked highest. The chord whose component tones were anchored immediately ranked next; immediate anchoring served to increase the stability of these tones relative to those whose anchoring was delayed.

EXPERIMENT 5

This experiment employed a recognition memory paradigm to test delayed anchoring. The melodies were adapted from Experiment 2 by interpolating a nonchord tone between the tone in the target position and the following tone. For example, if in Experiment 2 G–C was changed to B–C (B anchored) or to F–C (F not anchored), in the present exper-

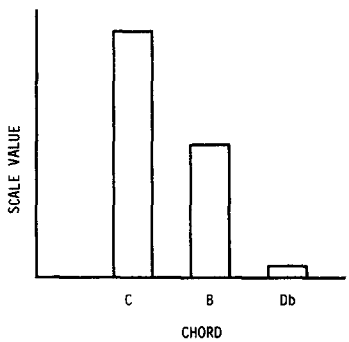

FIG. 9. When the components of C anchor the components of D^b in a delayed fashion and anchor the components of B immediately, C is the most preferred chord, followed by B and then D^b.

iment G–D–C was changed to B–D–C (B anchored in delayed fashion) or to F–D–C (F not anchored at all). The interpolated tone (D) was always anchored immediately. To equate the length of the melody in the two experiments (five tones), the addition of the interpolated tone required the removal of another tone in the sequence.

Method

Subjects. Fourteen Cornell students were paid $2 each for participating for 40 min. Subjects were recruited without regard to musical training. Five subjects reported having received no musical instruction at all; six reported 2 to 5 (an average of 3) years of instruction in elementary or junior high school but nothing since; three reported between 7 and 15 (an average of 11.3) years through high school or college. All subjects reported having normal hearing and none reported absolute pitch.

Apparatus and stimuli. The apparatus was the same as in Experiment 2. The standard-comparison melody pairs were adapted from Experiment 2 in the following manner. A nonchord tone was interpolated between the target position and the following chord tone, such that (i) the direction of motion (ascending or descending) from the interpolated tone to the following chord tone was the opposite of the direction from the target position to the chord tone and (ii) the interpolated tone was anchored immediately by the following chord tone. Once again, care was taken to rule out tone progressions that would instantiate some chord other than C, to ensure that the target was indeed being perceived as a nonchord tone and not simply a chord tone of another chord. Not all the sequences from Experiment 2 could be adapted with these constraints. The design was identical to Experiment 2 in all other respects.

Procedure. On each trial subjects heard a sequence of five tones (the standard melody) followed by another sequence of five tones (the comparison melody). Subjects indicated whether the two sequences were the same or different, and how confident they were of this judgment.

Results and Discussion

For the "different" trials, more confusions occurred when targets were anchored (.465) than when they were not (.581) ($F(1,13) = 23.61$, $p < .0005$). Thus, a nonchord tone is more easily confused with a chord tone if it is anchored in a delayed fashion than if it is not anchored at all. For the "same" trials, performance was better when targets were anchored in a delayed fashion (.844) than when they were not anchored (.814) ($F(1,13) = 47.88$, $p < .01$). The delayed anchoring effect was also borne out using areas under ROC curves. Targets that were anchored in delayed fashion were less likely to be detected (.692) than targets that were not anchored (.726) ($F(1,13) = 16.07$, $p < .01$). Nonchord tones are thus less conspicuous when anchored than when not anchored, even though the anchoring is delayed. Delayed anchoring is therefore reflected in memory judgments.

More confusions occurred when the target was in the standard melody (.396) than when it was in the comparison melody (.649) ($F(1,13) = 219.39$, $p < .0001$). This effect of presentation order was weaker when

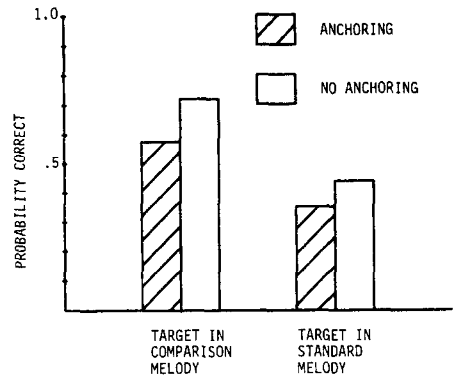

FIG. 10. More confusions occur when a chord tone is replaced by a nonchord tone that is anchored in a delayed fashion than by one that is not anchored at all.

the target was anchored than when it was not (see Fig. 10), as predicted, though the interaction was not significant.

Delayed anchoring rendered nondiatonic tones just as stable as diatonic tones that were not anchored (see Fig. 11). Unlike the memory experiment on immediate anchoring (Experiment 2), delayed anchoring did not render nondiatonic tones significantly more stable than diatonic tones that were not anchored. All subjects showed evidence of delayed anchoring, including those who reported no musical training at all.

EXPERIMENT 6

This experiment used the same rating task as Experiment 3 to test delayed anchoring. The same melodies were used as in the previous experiment (Experiment 5) except that they were accompanied by a chord.

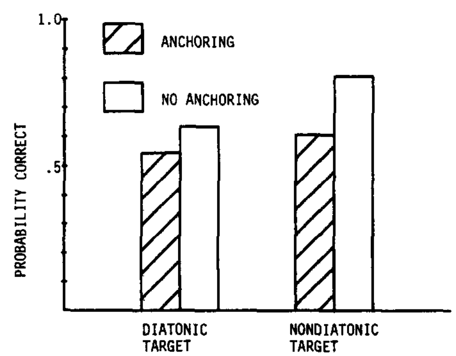

FIG. 11. An effect of delayed anchoring is seen for both diatonic and nondiatonic nonchord tones.

Method

Subjects. Six Cornell students were paid $2 for participating in one 30-min session. Two subjects reported having had no musical instruction. The other four subjects reported 2, 3, 8, and 12 years of instruction. All subjects reported having normal hearing and none reported absolute pitch.

Apparatus and stimuli. The apparatus was the same as in the previous experiment (Experiment 5). The sequences were taken from the previous experiment, but were accompanied by a C major chord. The chord consisted of C, E, and G an octave below the melody, and sounded continuously for the duration of the melody. The design was identical to Experiment 3.

Procedure. On each trial subjects heard a sequence of five tones with a chord sounding simultaneously in the background. The task was to rate, on a scale from 1 to 5, how well the sequence and the chord sounded together, or how musical the sequences sounded in the presence of the chord.

Results and Discussion

The raw responses of each of the six subjects correlated significantly ($\alpha = .01$) across the two replications. The chord tone melodies received the highest ratings (3.25), followed by melodies with anchoring (2.94) and then melodies without anchoring (2.70). Melodies with anchoring received significantly higher ratings than melodies with no anchoring ($t(5) = 2.97$, $p < .05$). This demonstrates that delayed anchoring is reflected in rating judgments. Melodies that contain nonchord tones that are anchored in a delayed fashion are perceived as being better accompanied by a chord than melodies that contain a nonchord tone that is not anchored at all.

GENERAL DISCUSSION

For almost any melody in Western music (except atonal melodies), a chord or sequence of chords can usually be found that would provide a fitting accompaniment; and if chords are not played along with the melody, one often hears them as if they were implied. This is in accord with Schenker's (1935/1979) claim, more recently elaborated as a generative theory (Lerdahl & Jackendoff, 1983), that Western melodies are represented psychologically in terms of their underlying harmony. On this view, chords (or chord functions) are abstracted from the melody by forming representations that include only the skeleton of chord tones. Nonchord tones are perceived to be subordinated to the chord tones to which they "resolve," i.e., to which they are anchored. It is suggested here that this abstraction process presupposes a principle of perceptual organization—melodic anchoring—by virtue of which the listener knows (tacitly), when presented with a melody without an accompanying chord, which tones to subordinate to which.

Melodic anchoring embodies two constraints. First, an anchor must follow the tone it anchors. This constraint is consistent with the perceived temporal asymmetry of tones differing in stability (Krumhansl, 1979). Second, the anchor and the tone it anchors must be pitch neighbors (chromatic or diatonic neighbors). This constraint is consistent with the privileged processing of a pair of tones that are proximal in pitch (Deutsch, 1978).

Immediate anchoring and delayed anchoring were each tested using three different experimental paradigms. The first paradigm demonstrated that melodic anchoring enables a listener to pick up information contained in the ordered relationships between tones in order to activate the appropriate tonal schema. In most music, the most stable tones tend to occur most frequently, and in highly stressed metrical positions. These two cues are usually available to the listener to activate a tonal schema; the tonal schema specifies a hierarchy of stability (a tonal hierarchy) which can then be used to classify subsequently encountered tones as either stable or unstable. The classification of each musical event (tone or chord) as stable or unstable as it is encountered is necessary in order for the listener to construct a hierarchical representation of the piece as a whole. Schenker (1935/1979), Deutsch (1980; Deutsch & Feroe, 1981), and Lerdahl and Jackendoff (1983) have argued that the perception of coherence in a piece of music consists in its being represented hierarchically. This hierarchy, a hierarchy of musical *events,* presupposes the representation of a tonal hierarchy. At the beginning of a piece, therefore, the listener must be able to use information in the music to generate the appropriate *tonal hierarchy* that will permit the construction of an *event hierarchy* (see Bharucha, 1984; Deutsch, 1984). If the distribution of tones or their relative metrical stress is not sufficient to activate the appropriate tonal hierarchy, the listener must rely on the temporal ordering of tones, using melodic anchoring as a guiding principle. The results of the first experimental paradigm used in the present study confirm the use of such a principle.

The second experimental paradigm demonstrated that melodic anchoring renders nonchord tones effectively more stable, thereby permitting their assimilation to the tonal schema. In a same-different recognition memory task, more confusions occurred when a chord tone was replaced by a nonchord tone that was anchored than by one that was not. A nonchord tone that is not anchored is thus more perspicuous. Anchoring was found to be powerful enough to admit even nondiatonic tones to the fold. "Chromaticism" in Western tonal music involves the introduction of nondiatonic tones that are then anchored. Furthermore, a failure to anchor was found to be more conspicuous in the standard sequence than in the comparison sequence of the memory task. The existence of an unanchored unstable tone in the standard sequence reduces the specificity of the activated tonal schema, thus compromising the accuracy of the matching process when the comparison sequence comes along. This difference in confusion rates as a function of presentation order was decreased when the unstable tone was anchored.

In the first two paradigms, a chord was never explicitly sounded along with the melody. The results thus demonstrate that an underlying chord was being inferred. The final paradigm involved the explicit accompaniment of the melody by a chord, the most common musical scenario. As predicted, accompaniments were judged more appropriate when nonchord tones were anchored than when they were not.

For any candidate chord, the principle of melodic anchoring identifies the tones in the melody that are stable, and determines whether the other tones satisfy the criteria for either immediate or delayed anchoring. If the prior context has already determined which tones are stable and which are not (by the activation of a tonal schema), the only determination to be made is whether or not the unstable tones are anchored. If no prior context exists, melodic anchoring computes the chord that gives the best fit, i.e., the chord with respect to which as many of the tones in the melody as possible can be classified as either stable tones or anchored unstable tones.

There certainly exist melodies that cannot be parsed so as to give a perfect fit to the principle. It is suggested here that in such melodies, the tones that do not satisfy the principle will interfere with the tonal schema that is activated, if one is activated at all. The memory experiments, for which the data were the most robust, provide an objective characterization of interference. This is important because discord may sound musical to a listener of atonal music. The same-different judgments in the memory paradigm were either right or wrong. Hence melodic anchoring as an organizational principle in cognition can be characterized independently of musical taste.

Unstable chords seem also to be anchored by stable chords, a principle we may call harmonic anchoring. Both harmonic anchoring and melodic anchoring are characterized by an asymmetry constraint—the anchor always follows the anchored. However, whereas melodic anchoring requires that the anchor and anchored be proximal in pitch, harmonic anchoring would require that they be proximal in their peculiarly harmonic relationship.

In Western music, the tones of a melody that can best serve as anchors are the component tones (chord tones) of a chord that would standardly accompany that segment of the melody. It is likely that anchoring effects also characterize the perception of forms of music (such as Indian music) that are not based on harmony. In these cases the anchor tones would be those tones designated as stable by the tonal hierarchies of those cultures.

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