THE EFFECT OF MUSICAL EXPERIENCE ON THE PERCEPTION OF TRIADS

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By

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ABSTRACT

Historically, music theorists have claimed that the major triad functions as a strong instantiator of key, and that each of its inversions are harmonically equivalent. To examine these assumptions, subjects were tested with the Method of Paired Comparisons, and asked to judge the similarity of root, first inversion, and second inversion major triads drawn from keys of different degrees of musical relatedness. In Experiment 1, where triads were built on the tonics of two maximally-related keys (A and E major), only professional musicians demonstrated a separation of the triads on the basis of key, indicating that inversions of triads built on the same root-note were perceived as sounding similar to one another. The majority of moderately-trained and inexperienced subjects tended to use a pitch-height strategy, in which triads containing upper notes that were close in absolute frequency were judged as sounding similar to one another. In Experiment 2, where triads were also included from a distantly related key (Bb major), the majority of professional musicians continued to group all triads on the basis of key, while some moderately-trained subjects confused the maximally-related keys, but perceived them as distinct from the more distant key. Other moderately-trained and musically-inexperienced subjects used a pitch-height strategy for judging similarity. In Experiments 3 and 4, chords were built on seven different root-notes moving counterclockwise and clockwise, respectively, from a constant standard chord on the Circle of Fifths. The professional and moderately-trained subjects tested did not show an especially strong tendency to judge chord similarity on the basis of musical key in either experiment. Inversion equivalence was demonstrated in each of these four experiments by subjects who judged triads built on the same root-note as sounding similar to one another. In Experiment 5, where seven Shepard chords (chords built to obscure pitch-height and inversion cues) were presented to only moderately-trained subjects, similarity judgements now appeared to be based on key. Conclusions are made regarding musical representation in a form described by the theoretic Circle of Fifths in musically-trained individuals.

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CHAPTER I

INTRODUCTION

Musicians learn very early in their careers that music is a highly organized system of relationships between tones. During musical training, an individual discovers that the pitch associated with a tone does not merely correspond to a particular physical frequency, but that it also possesses meaning in terms of its relative musical importance to the other tones in a composition. Through the manipulation of these relationships between tonal elements, which are considered to have different functions within the music, feelings of tension and resolution can be created by the composer. Musicians are sensitive to these differential functions as evidenced by their ability to anticipate musical events. Whether or not these expectations are fulfilled determines whether an ensuing satisfaction or uneasiness will be experienced (Meyer, 1956).

Awareness of the tonal and chordal functions underlying musical composition does not appear limited to highly-trained musicians. Even a musically-naive individual would feel uncomfortable ending a familiar tune prematurely: "Row, row, row your boat, gently down the stream--." This is partly because a musical key has been established within the span of the first few notes, making it clear to the listener that the note corresponding to "stream" was not the tonic of the key, the more probable ending for a composition based on Western harmony. Another example of a nearly universal cognizance of musical rules is the acute awareness of a "sour note," or note outside of the established key, when it is sung or played.

Despite the apparent pervasive awareness of these rules, whether in the form of implicit or explicit knowledge, they are highly complex. The music-theoretic rules underlying lawful harmonic combinations in Western music describe permissible combinations of tones. They describe the circumstances under which certain musical elements are considered stable (not demanding resolution to other tones or chords), or unstable (combinations needing to be resolved by more satisfactory musical elements). These permissible combinations are dictated by the musical key in which a composition is written, with the assumption of the existence of hierarchies of tonal and chordal functions both within a key, and between keys. For example, within a key, the I, IV, and V chords, and I, III, and V tones are considered very stable. Between keys, keys that are the distance of a musical fifth apart are considered highly related, and tones from outside the key, called nondiatonic, are not considered stable entities within the key. This abounding complexity makes questionable the level at which highly-skilled musicians access these rules, and makes even more questionable the level at which musically-inexperienced individuals appeal to them. For example, both musically- experienced and inexperienced individuals would be expected to have an awareness of the occurrence of a sour note, but whether individuals from both groups would be able to select, what is in theory, the more musically appropriate alternative for the sour note, is debatable. Furthermore, these theoretic assertions are a conglomeration of ideals, descriptors, and guidelines for composition within a particular musical system, that are further bound by a particular culture and era, but there is little empirical support that these theoretic guidelines reflect perceptual practice (see Krumhansl, Bharucha, & Kessler, 1982).

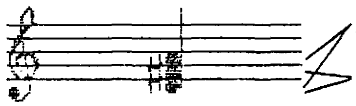
Two major issues arise from these observations. One concerns whether these theoretical rules adequately describe the perceptual experience of music. The other concerns the question of who, if anyone, adheres to these rules. It would seem that the musically naive possess at least a superficial awareness of musical standards, and certainly the musically trained would be expected to have a more detailed knowledge base. However, if these theoretical rules do not have a firm basis in perception, then perhaps in practice even musically-inclined individuals remain unaware of their explicit dictates during music perception.

It was the purpose of the present thesis to investigate one highly visible aspect of music perception, the basis on which all of Western harmony is built and the focus of a considerable number of theoretical assertions--major tonic triads. A triad is defined as the simultaneous or sequential presentation of three tones. Triads can be built on any note, called the root of the triad, and it is the root which gives the triad its name. For example, a triad built on an A would be called an A-triad. Adding notes to the root, which occur in certain musical intervallic relationships to the root, determine the type of triad to be formed (e.g., major, minor, augmented, diminshed). A triad containing the root as the lowest note, with an additional note the distance of a major third above the root, and one note the distance of a perfect fifth above the root is called a major triad. Another way to think of these intervallic relationships is in terms of the ratios between the tonal frequencies which combine to form them. The ratio of the frequency of a tone that is a major third above the root to the frequency of the root is 5:4; whereas, for a tone a perfect fifth above the root, this frequency relationship is 3:2. The intervallic relationships and frequency ratios between the tonal components for minor, augmented, and diminished triads, along with major triads, are shown in Figure 1.

Triads can occur in different inversions or positions. If the lowest tone is the root, such that the intervals of a third and a fifth occur above the root, then the triad is said to be in root position. The notes which combine to form the triad, from lowest to highest, are called the root, third, and fifth. By placing the root an octave higher so that the third is now the lowest tone, the interval of a third is formed between the lowest and middle note (frequency ratio of 5:4), with the interval of a minor sixth formed between the lowest and highest notes (frequency ratio of 8:5). Such a triad is said to be in first inversion. Going one step further, by now placing the third an octave higher, a triad will be formed in which the intervals above the lowest note will be those of a fourth with the middle note (frequency ratio of 4:3), and a major sixth with the top note (frequency ratio of 5:3). This triadic position is called second inversion. Figure 2 shows the intervallic relationships for the three triadic positions.

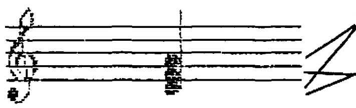
Triad perception is clearly related to the perception of musical key. Musical key can be best understood by examining the scales that define key. Major scales can be built on any of the 12 chromatic tones of an octave, as long as the spacing between the 8 tones of the resulting scale is of the pattern: tone-tone-semitone-tone-tone-tone-semitone. A semitone is the smallest interval

Figure 1. Intervallic relationships and frequency ratios between triadic tones for major, minor, augmented, and diminished triads. (These relationships are given for just intonation. See Roederer, 1979, p. 154-155.)



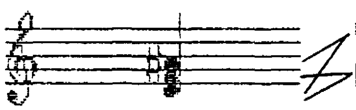
PERFECT FIFTH (3:2)
MAJOR THIRD (5:4)

MAJOR TRIAD



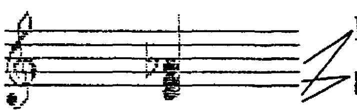
PERFECT FIFTH (3:2)
MINOR THIRD (6:5)

MINOR TRIAD



AUGMENTED FIFTH (25:16)
MAJOR THIRD (5:4)

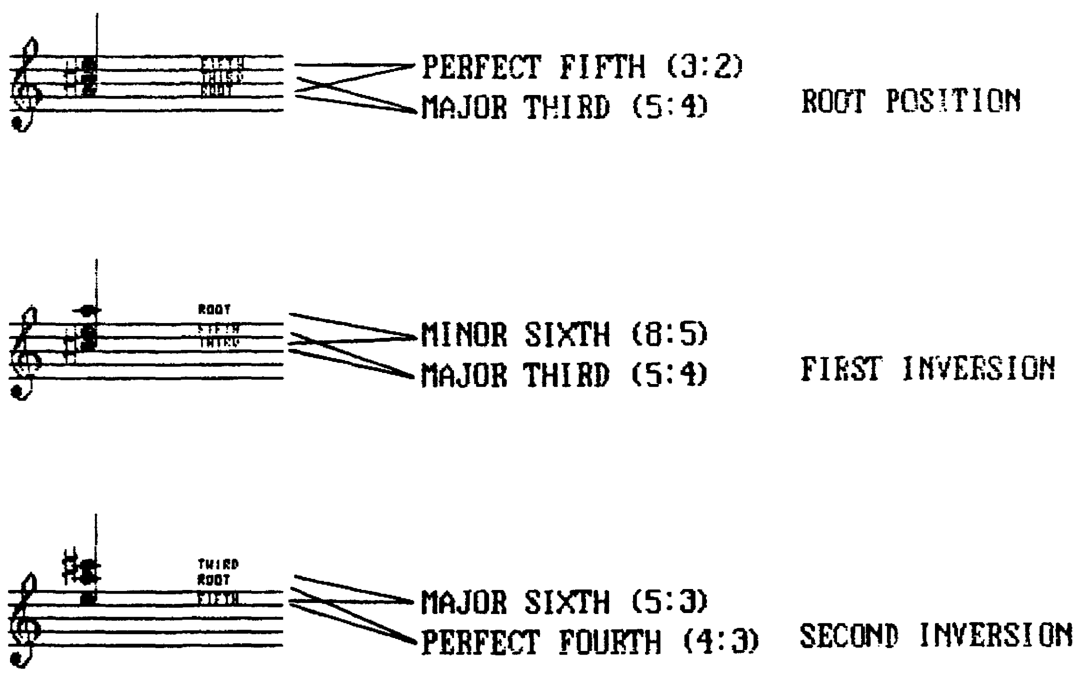
AUGMENTED TRIAD



DIMINISHED FIFTH (45:32)
MINOR THIRD (6:5)

DIMINISHED TRIAD

Figure 2. Intervallic relationships and frequency ratios between triadic tones for root position, first inversion, and second inversion triads.

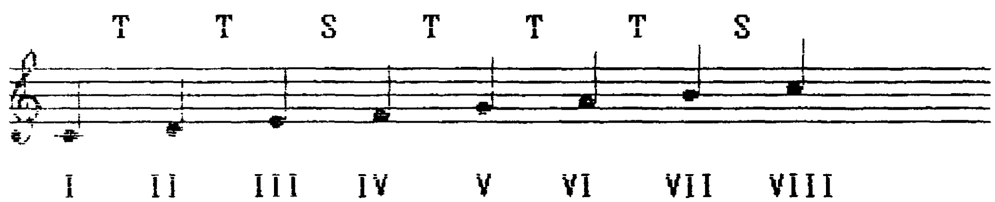


FIFTH
THIRD
ROOT
PERFECT FIFTH (3:2)
MAJOR THIRD (5:4)
ROOT POSITION
ROOT
FIFTH
THIRD
MINOR SIXTH (8:5)
MAJOR THIRD (5:4)
FIRST INVERSION
THIRD
ROOT
FIFTH
MAJOR SIXTH (5:3)
PERFECT FOURTH (4:3)
SECOND INVERSION

that can occur between two pitches in traditional Western music, and is represented by the distance between an adjacent white and black key on a keyboard instrument. A tone is equivalent to the distance of two semitones. Scales which conform to these patterns are called diatonic scales, and each tone comprising the scale is called a diatonic tone. Each scale degree is assigned a Roman numeral from I through VIII, and is also assigned a specialized name: I (tonic), II (supertonic), III (mediant), IV (subdominant), V (dominant), VI (submediant), VII (subtonic), VIII (tonic, which is the same tonic as I). Tones that are not scale members are called nondiatonic. Figure 3 shows an example of a major scale.

Each note of the scale has a designated role of importance within a melody. The terms stability, importance, and significance, when used in the present thesis to describe relationships between tones, will refer to the concept of tonal function. A tonal function is defined in terms of a tone's relative stability within a musical key, or need for resolution, in comparison to the tonic. Different tones are considered to have different degrees of need for resolution; and therefore, their tonal functions can be thought of in terms of a hierarchy of function. The tonic is considered the most stable and significant tone, since it defines the tonal center of a musical work. The tonal center is what gives a melody its sense of key, and it is theoretically the tone to which all other tones, whether scale tones or not, will gravitate. For example, when singing the following scale: do-re-mi-fa-sol-la-ti-_, there is a compelling urge to sing the last note as do, which is the tonic. Less satisfaction would probably be reported if re (scale degree II) was inserted into the final scale position. The next most

Figure 3. C-major diatonic scale.



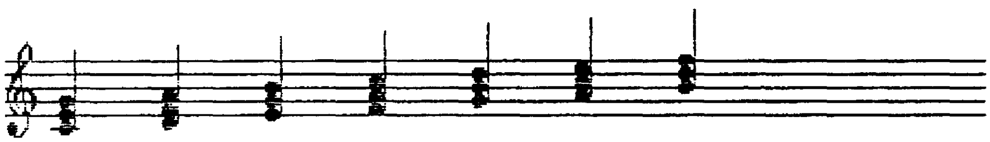
T = TONE
S = SEMITONE

I = TONIC
II = SUPERTONIC
III = MEDIANT
IV = SUBDOMINANT
V = DOMINANT
VI = SUBMEDIANT
VII = SUBTONIC
VIII = TONIC

important tone, according to music theoretic principles, is the dominant, or V note of the scale, followed by the mediant, or III note. Together, the tonic (I), dominant (V), and mediant (III) comprise the major tonic triad, and contribute to a "firm and pleasant impression of a tonal center, [and] absolute effect of stability" (Ratner, 1962, p. 19). Next in order of importance are the remaining diatonic tones, and then the nondiatonic tones.

There also exist differential theoretic stabilities for the chords built on different degrees of the scale, resulting in different chordal functions. Each of these chords is assigned the same Roman numeral and specialized name as the scale degree which serves as its root, and is built by adding tones at the intervals of a third and a fifth above each scale tone. When the tonic of a major scale serves as the root of a major triad, the triad is labelled a major tonic triad, and it is considered the most stable of all triads. Next most stable are the triads built on the dominant (V) and subdominant (IV) scale degrees, which are also major triads. Together these three triads firmly establish a sense of key because, taken as a unit, they contain all the notes of the major diatonic scale from which they are built. The next most stable chords, in order of descending degree of importance, are the VI, II, III, and VII chords. The VI, II, and III chords are each minor chords, because the intervals above the root are those of a minor third and perfect fifth, the intervals which define minor triads. The VII chord is called diminished, because it is composed of a minor third and a diminished fifth. An example of the chords built on each degree of a C-major scale is shown in Figure 4. If the notes of a chord are diatonic, then that chord is considered a diatonic chord. Chords that use tones outside the scale are

Figure 4. Triads built on each degree of a C-major diatonic scale.



I II III IV V VI VII

MAJOR MINOR MINOR MAJOR MAJOR MINOR DIMINISHED labeled nondiatonic.

A musical key is what compels one to end a musical composition on a particular note, and gives the feeling that a particular note serves as a pivot point or reference to which all others are subordinate. This reference note is the tonic, and the tonality of a musical composition is usually established by playing the tonic at the beginning and end of a piece (Goldman, 1965; Siegmeister, 1965), and by giving it greater rhythmic emphasis by either accenting it or playing it for a longer duration relative to other tones (Ratner, 1962). Also, the tonic tends to occur at the ends of large phrases (Krumhansl & Kessler, 1982), and it is usually played more often than any other tone in the composition. Once a tonality is firmly set forth within a musical selection, certain expectations are created regarding which notes are stable or unstable with respect to the tonality. For example, in the demonstration of singing a scale and ending one note before the tonic, there is a tendency to report a certain uneasiness about terminating the scale at this point. It is not until the tonic is sung that a sense of finality is invoked.

Keys can be either closely or distantly related. Krumhansl, Bharucha, and Castellano (1982) stated that key distance could be measured by the number of tones in common between the two scales of the keys, the number of sharps or flats in common in the key signature, or the distance around the Circle of Fifths (see Figure 5). The Circle of Fifths is a convenient device by which each of the twelve major and twelve minor keys are represented on a circle, such that each successive key is a musical fifth away from the preceding key. Neighboring keys share many of the same notes and chords, and are thus

Figure 5. The Circle of Fifths for the 15 major keys (including 3 enharmonic keys).

CIRCLE OF FIFTHS

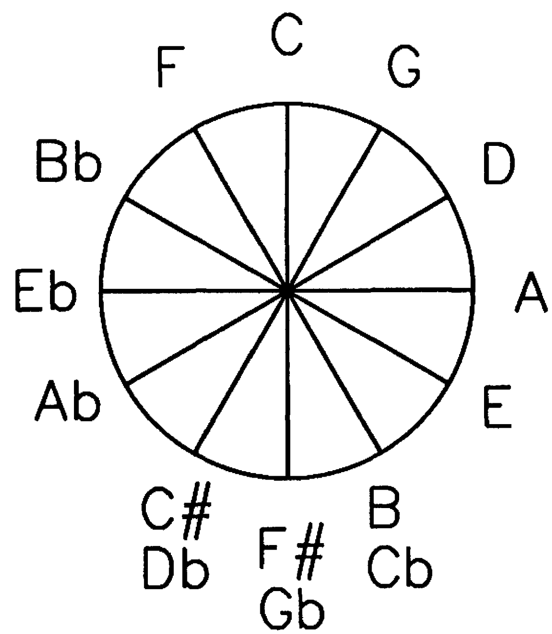
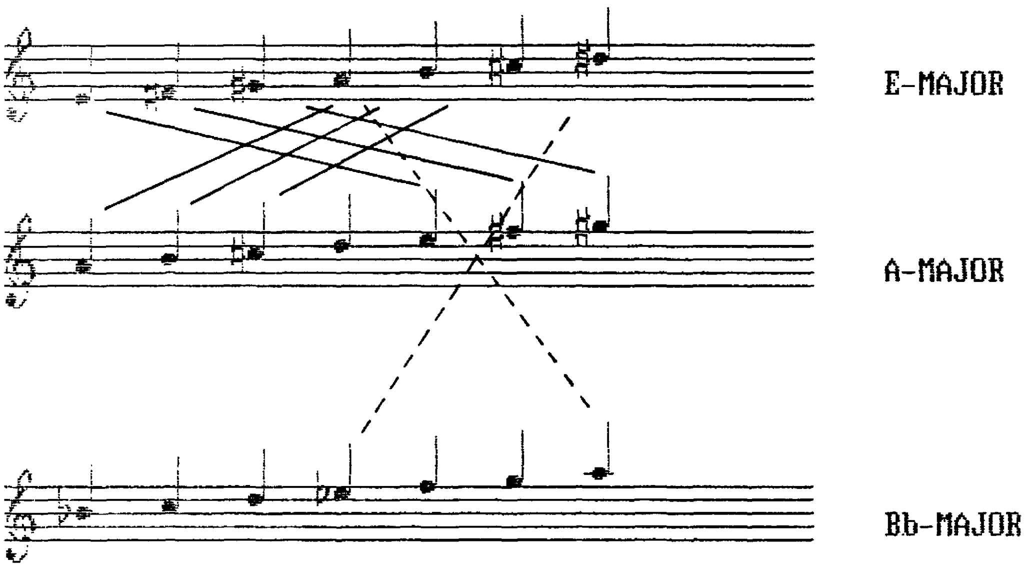
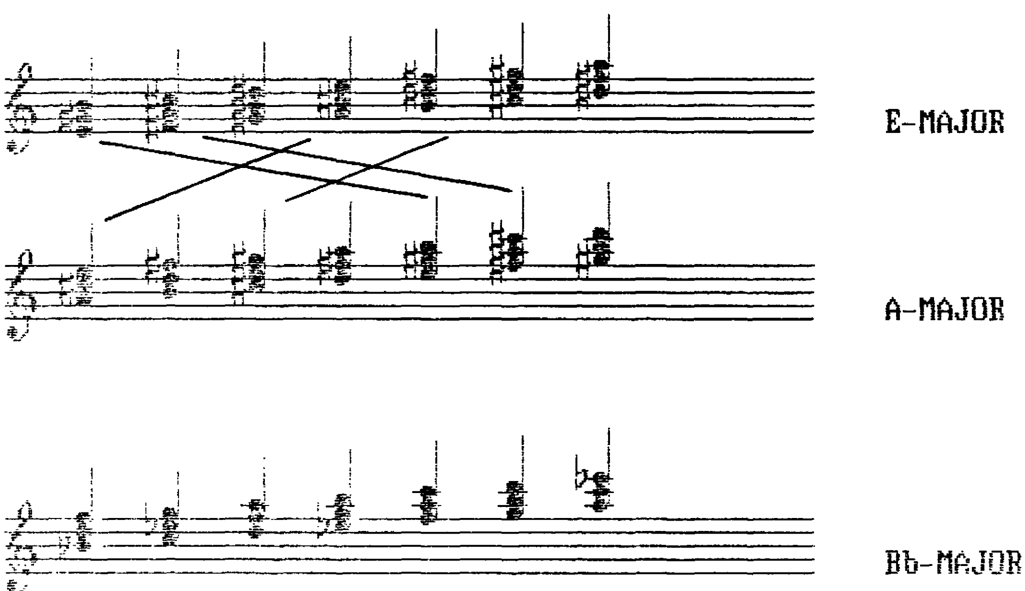


Figure 6. Shared tones and chords between two maximally-related keys, A major and E major, are shown. Shared tones and chords between two maximally-distant keys, E major and Bb major, are also shown.


E-MAJOR
A-MAJOR
Bb-MAJOR


E-MAJOR
A-MAJOR
Bb-MAJOR

considered highly related. For example, Figure 6 shows the scales and chords from E and A major, two highly-related keys which are represented in adjacent locations on the Circle of Fifths. These keys share all but one note and four of a possible seven chords, an example demonstrating that notes and chords possess multiple harmonic functions. This overlap of notes and chords between keys leads to some ambiguity in determining the key from which a triad is drawn, although theorists claim some tendency for triads to be interpreted as the tonic triads of their respective keys in a process called tonicization (Krumhansl & Kessler, 1982; Randel, 1978; Schenker, 1906/1954). As one moves further around the circle from an arbitrarily selected key, one moves to what are considered more distant keys, or keys that do not have many notes or chords in common with that selected key (see Forte, 1979, pp. 27-28; Hepner, 1979, pp. 43-44, 156-158). For example, as is also shown in Figure 6, the two maximally distant keys of E major and Bb major share only two scale notes and have no chords in common.

Knowledge of the relationships between keys is a necessary condition to effectively produce a modulation, or change of key. Key changes most often occur between keys that are closely related (Randel, 1978), in particular, to keys that are adjacent on the Circle of Fifths, or the distance of a musical fifth apart (Forte, 1979; Hepner, 1979). The reasoning behind these close modulations is to avoid abrupt changes in the musical flow, and to add variation without completely destroying the tonal and chordal relationships which were established in the original key (see Forte, 1979, p. 266). Furthermore, to facilitate smooth transition, modulation usually occurs through the use of a pivot chord, or chord that is shared between the old and new keys, and this is more readily accomplished between keys that are closely related.

Music theorists have claimed that major tonic triads play an extensive and fundamental role in Western tonal music by providing a strong sense of musical key (Kohs, 1961; Ratner, 1962), a feeling of stability throughout musical selections (Kohs, 1961), and a firm impression of finality at the end of compositions (Kohs, 1961; Ratner, 1962; Siegmeister, 1965). Perhaps most important, however, is the claim made by theorists that these three notes can perform these functions, and establish themselves as prototypes toward which entire musical compositions are judged, in the absence of any other musical context (Ratner, 1962). Presentation of only the three tones comprising a major triad should, in theory, invoke a strong sense of stability and key without any other musical stimuli for comparison. Theoretic principles also exist which specify the supposed relatedness between triads built on the tonics of different musical keys, as exemplified by the Circle of Fifths. Furthermore, theorists have claimed that under many musical circumstances, the three inversions, or positions in which the three tones can be sounded simultaneously, are considered musically equivalent to one another.

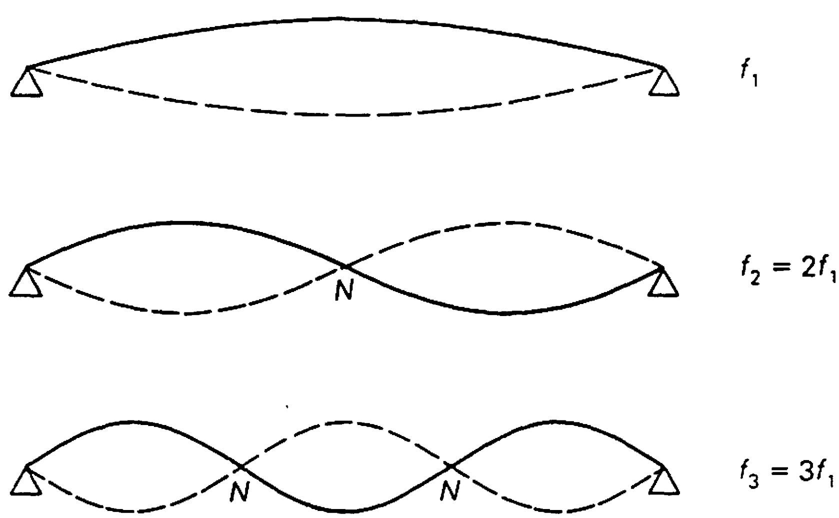
Given the theoretical proclamations that major triads play a critical role in Western composition, that these three tones in isolation are capable of becoming standards to which other notes and chords are related, and that triads voiced in different positions are harmonically equivalent to one another, it seemed essential to investigate the perception of these chords to determine if these claims could be empirically substantiated. In particular, the five studies of the present thesis were an attempt to discern the perception of musical key relationships, as revealed through presentations of major triads, and then relate these perceptual experiences to the principles advanced by music theory. Additionally, these investigations involved individuals of diverse levels of musical expertise, in efforts to determine whether or not musical triad perception was dependent on formal musical training.

Major Triads: Background and Theory

Harmonic Series

One reason why major triads have been regarded as so central to Western music is because of their derivation from a harmonic series. A harmonic series is most simply represented in terms of the standing waves produced by vibrations of an ideal string (i.e., a string which is uniform and flexible, and offers no resistance to vibration). When such a string is anchored at both ends and then set into motion, the resulting vibration can be thought of as the first mode of vibration, or the fundamental frequency (f_1). This fundamental frequency is most likely the pitch one would report hearing when presented with a sine wave. If this ideal string is then divided in half by placing an additional anchoring point, or node, in the middle of the string, the second mode of vibration would be established and a pitch corresponding to two times the frequency of the fundamental (2f) would be heard. By continuing to add nodes which divide the string into integer multiples of the fundamental frequency, the reported pitches would be those corresponding to vibrations that are integral multiples of the frequency of the fundamental (3f, 4f, 5f, and so on), with such a collection of frequencies labeled a harmonic series. Figure 7

Figure 7. Three vibration modes for an ideal string. Nodes (N) represent stationary points on the string. Adapted from Musical Acoustics (p. 174) by D.E. Hall, 1980, Belmont, California: Wadsworth Publishing Company.

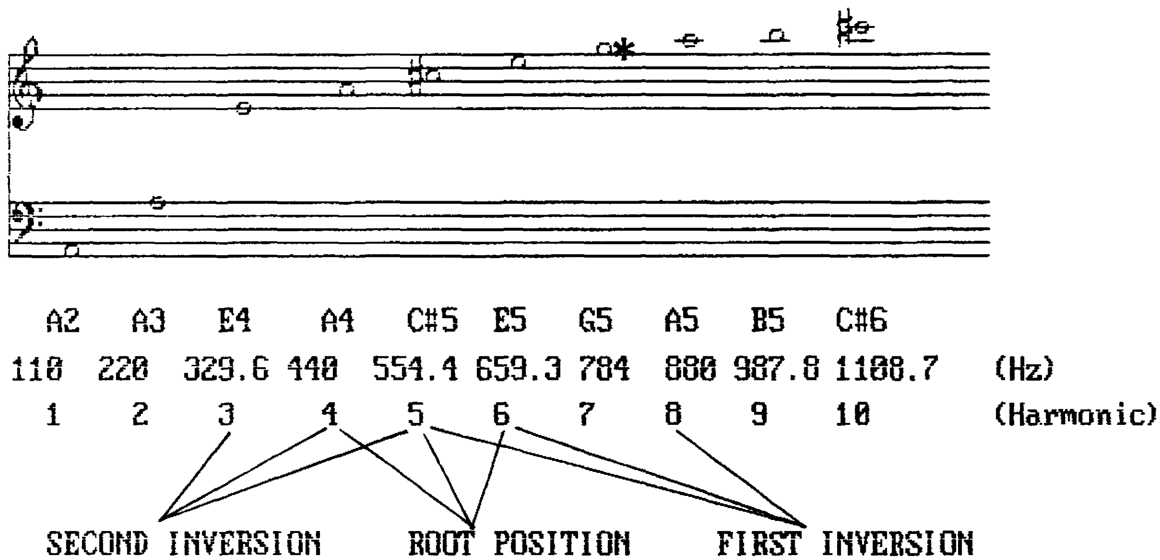

f_1
N
$f_2 = 2f_1$
N
N
$f_3 = 3f_1$

illustrates the division of a string, resulting in a number of vibratory modes. Musically, modes are very important since most musical instruments, whether strings, wind, or human voices, produce pitches comprised of harmonic series that are whole-number integer multiples of a fundamental frequency. So pervasive, in fact, is this phenomenon that Erickson (1982) dubbed the harmonic series the "chord of nature."

The significance of whole-number relationships to the fundamental frequency becomes apparent in the observation that the modes can be expressed in terms of their musical-interval relationships to the fundamental. The intervals that are formed with the series fundamental are described as "natural," or "harmonic" or "acoustically pure" (Randel, 1978). Figure 8 exemplifies a harmonic series for the fundamental A_2 (110 Hz). The fundamental frequency, f_1, is the first harmonic. The second harmonic, f_2 (2 x 110 Hz), is an octave higher. The third harmonic, f_3 (3 x 110 Hz), is a twelfth above f_1 (a musical fifth above f_2). The fourth harmonic, f_4 (4 x 110 Hz) is two octaves above f_1. The fifth harmonic, f_5 (5 x 110 Hz) is a seventeenth above f_1 (a musical third above f_2). The higher harmonics can be found by continuing to multiply the fundamental frequency by successively higher integers, and the intervallic relationship to the fundamental can then be deduced.

Regarding the major triad and its association with the harmonic series, one can see in Figure 8 that without skipping any notes in the series, the first six harmonics of a fundamental frequency (f_1) are all major triad components. Furthermore, the third, fourth, and fifth harmonics are the lowest numbered harmonics in the series in which all three triad components are

Figure 8. Harmonic series for fundamental frequency A_2. The harmonics corresponding to each of the triadic positions for an A-major triad are shown. (Note that the frequency of the seventh harmonic does not match the frequency expected for that note in equal temperament tuning.)


A2 A3 E4 A4 C#5 E5 G5 A5 B5 C#6
110 220 329.6 440 554.4 659.3 784 880 987.8 1108.7 (Hz)
1 2 3 4 5 6 7 8 9 10 (Harmonic)
SECOND INVERSION
ROOT POSITION
FIRST INVERSION

present in close form.[1] These components correspond to a pattern of intervals of a fourth and sixth, as measured from the lowest note of the triad, representing a major triad in second inversion. A root position major triad in close form can be found as the fourth, fifth, and sixth harmonics, with these harmonics combining to form the intervals of a third and a fifth as measured upward from the root of the chord. A first inversion major triad in close form appears as the fifth, sixth, and eighth harmonics of the series. These harmonics comprise the intervals of a third and a sixth as measured upward from the lowest note of the chord. It is interesting that Plomp (1964) found that the first eight harmonics could be heard-out individually, and eight harmonics are required to obtain all three triadic positions.

The Missing Fundamental Phenomenon

A peculiar manifestation of a harmonic series is that it provides a strong sense of the fundamental frequency of that series. During production of a complex tone, a number of harmonics, or overtones, will be generated, but pitch assignment will be that of the series fundamental. This sense of the fundamental is so convincing, that the first harmonic can be eliminated from presentation of a series, and a strong impression of the series' fundamental will still remain. The presence of a corresponding pitch sensation, despite the fact that the fundamental frequency is not physically present, is referred to as the missing fundamental phenomenon. The missing tone itself is called the missing fundamental or fundamental root, and the pitch sensation is labeled virtual pitch.

Benade (1976) gave a specific example of missing fundamental detection. By first listening to sinusoidal frequencies of 220, 440, 660, 880, 1100, and 1320 Hz presented simultaneously, subjects reported a pitch of 220 Hz. After removing the fundamental frequency (220 Hz) and the second harmonic (440 Hz), subjects still reported a pitch corresponding to 220 Hz. By further removing all frequencies except for the highest two, subjects continued to report a pitch sensation of 220 Hz (see also Backus, 1969; Hall, 1980; Roederer, 1979). Because the upper harmonics of a fundamental frequency occur in integer multiples of that fundamental frequency, playing two successive harmonics is apparently sufficient to cue a pitch sensation corresponding to the fundamental.

As early as the sixteenth century, the perception of this physically absent frequency was used in the construction of organs to create a richer sound quality (Roederer, 1979). By including a stop in the organ pipes to produce a sound a fifth higher than the note actually played, two sounds comprising a musical fifth would be produced, and would imply a bass note (fundamental) one octave below the sounding note. A present-day demonstration of the missing fundamental's psychological reality is the perception of piano tones as low as 27.5 Hz on an inexpensive radio, although the radio itself is not capable of producing audible frequencies below 200 Hz (Benade, 1976). There have even been songs written, composed entirely of upper harmonics and no fundamentals, yet subjects report hearing perfectly reasonable sounding melodies (Licklider, 1954).

Studies have been conducted to determine how the various harmonics contribute to virtual pitch perception. Plomp (1967), for example, compared the relative importances of the fundamental to the upper harmonics of a complex for perception of this pitch. He reasoned that if the fundamental was most critical for the pitch perception, then a 10% frequency decrease in the fundamental should affect the perception more than a simultaneous 10% increase in the higher harmonics. This was measured by having subjects make judgments as to whether one of two successively presented sound complexes was higher in pitch. Results were then obtained for the percent of trials on which a subject perceived a pitch shift, when that pitch shift was a result of a frequency shift in the higher harmonics. Plomp's data indicated that for fundamental frequencies less than 1400 Hz, the second and higher harmonics were dominant for fundamental frequency perceptions; whereas above 1400 Hz, the fundamental itself was the dominant cue for perception. Furthermore, harmonics of three and higher were implicated for fundamental perceptions less than 700 Hz, while the fourth harmonics and above were important for fundamental perceptions less than 350 Hz. Taken together, these findings indicate that as the fundamental shifts to higher frequencies, the lower harmonics become more important to their perception.

Ritsma (1967) performed a similar investigation by manipulating the frequency components from both high and low frequency bands implying different fundamentals, and having subjects judge which of two stimuli was higher in pitch. By gradually filtering out the higher and/or lower harmonics of the low frequency band while subjects made high/low judgments, it was determined that the third, fourth, and fifth harmonics were the most influential for the establishment of pitch, at least for fundamental frequencies between 100 and 400 Hz. In other words, if a pitch shift occurred as a result of manipulation of harmonics within the so called "dominant region," as compared to a shift resulting from a change in harmonics not in the dominant region, subjects' judgments as to direction of the pitch shift tended to correspond to the shift produced in the dominant region.

The importance of these results with regard to major triad perception becomes apparent if the major triad in root position, which is claimed as the most stable triadic position, is considered to be comprised of the fourth, fifth, and sixth harmonics of a missing fundamental two octaves below its root. These harmonics are very close in number to those found in the dominant region of harmonics contributing most to fundamental perception, leading to speculation that the major triad may be dominated by a percept corresponding to the fundamental pitch. This speculation is further substantiated by the observation that the three tones comprising a major triad can be considered successive harmonics of a fundamental, and it has already been stated that the presence of only two successive harmonics is sometimes sufficient for fundamental perception.

A number of investigators have concluded that the occurrence of the missing fundamental is not due to nonlinear distortions in the peripheral system. Roederer (1979) cited evidence that the fundamental frequency could not be detected in cochlear fluid oscillations. Also, Small (1970) mentioned studies in which he participated and found that even by presenting noise in an effort to mask the area of the basilar membrane which would be predicted to respond to the missing fundamental, it was still reported (see also Licklider, 1954). Probably the most convincing evidence comes from Houtsma and

Goldstein (1972), who found that perception of the missing fundamental occurred even when each component of a two-tone complex was presented dichotically, indicating that the fundamental's inception must occur as a result of some centrally-mediated process.

Several models have been developed which describe a central mediation of pitch assignments for complex signals (Goldstein, 1973; Terhardt, 1974; Wightman, 1973). These models have in common the proposal of a central pitch processor, which functions to identify patterns of peripheral stimulation so that stimuli with common patterns are recognized as the same pitch. The central pitch processor is useful in that it explains why complexes with different patterns of harmonics, or those with missing fundamentals can be identified as the same pitch. Such a proposal assumes some type of stored template to which various stimulation patterns on the basilar membrane can be compared. When matches between the basilar membrane excitations and the template are made, even if all the components are not present, a most probable pitch can be derived. As a consequence of the results of Houtsma and Goldstein (1972), who found that components of a complex stimulus could be presented dichotically while still allowing fundamental pitch to be determined, it is assumed that the pitch processor is located somewhere in the system beyond the site where information from the two ears is brought together.

Terhardt's (1974, 1978, 1984) model of a central pitch processor makes a number of predictions regarding the perceived pitch of a tonal complex, such as a major triad. Terhardt made the distinction between spectral pitch, the pitch of a pure tone, and virtual pitch, the pitch of a complex tone. In order to ascertain pitch assignments for each of these different types of pitch, he proposed an analytic processing for spectral pitch and a synthetic processing for virtual pitch. The analytic mode associated with spectral-pitch determination is assumed to be dependent on which pure-tone components are present in the signal, and the relative intensities of those components. The "hearing-out" of individual harmonics comprising a complex tone is an example of analytic listening, a task which can usually be performed for the first eight harmonics (Plomp, 1964). Virtual-pitch assignment, on the other hand, results from a learning process. That is, one is assumed to learn to identify speech sounds and the harmonic relationships between their spectral components, such that information about these arrangements can be used when making judgments about the fundamental pitches associated with various acoustic stimuli. Terhardt exemplified the advantages of this learning by comparing the processing of sounds with that of visual stimuli. In vision, one is often presented with stimulus material which is incomplete--a corner of a square may be obstructed from view, or the letter of a word may have faded--yet because of prior learning one is capable of perceiving the gestalt and correctly reporting the presence of a square or an entire printed word. Terhardt's argument extends to such acoustic phenomena as the missing fundamental, where the presence of only a few harmonics may be sufficient for generating the report of a virtual pitch corresponding to a physically-absent fundamental.

The arrangement of stored auditory information in Terhardt's model takes the form of a matrix in which spectral-pitch cues associated with particular virtual-pitch cues are linked. These cues consist of the subharmonics associated with each resolvable spectral component of a complex sound. By resolvable is meant the ability for the component to be heard-out individually. Associated with each resolvable component will be a number of subharmonics, and the model predicts that the greatest number of occurences of a subharmonic determines the perceived pitch of the sound complex. For example, to determine the perceived pitch of 440 Hz and 660 Hz tones presented simultaneously, a number of subharmonics for each component must be calculated so that they can be examined for coincident subharmonics. Subharmonics are found by first dividing the resolvable component by a factor of 2, then by a factor of 3, a factor of 4, and so on (this can be thought of as the opposite of the operation for determining a harmonic series, in which the fundamental is first multiplied by a factor of 2, then a factor of 3, a factor of 4, and so on). In the present example, the first six subharmonics for 440 Hz would be 220 Hz, 146.7 Hz, 110 Hz, 88 Hz, 73 Hz, and 62.8 Hz; whereas those for the 660 Hz component would be 330 Hz, 220 Hz, 165 Hz, 132 Hz, 110 Hz, and 94.3 Hz. As can be seen, 110 Hz should be the virtual pitch assigned to the sound complex because it is the pitch associated with the maximal number of activated cues. If there is no common subharmonic shared between the components, the closest match of a common subharmonic is predicted to correspond to the virtual pitch. This model allows for the processing of spectral cues to occur at a peripheral level, but all other pitch processing, such as virtual pitch assignment, is considered a central phenomenon.

The central-pitch-processor theories, regardless of their mechanisms, are all based on the theory that somewhere in the brain an attempt is made to make a "best match" between the physically presented spectrum and a stored harmonic series, in order to predict a fundamental frequency. These theories imply that the central pitch processor is better able to make matches between stimuli whose harmonic series are very similar to those already stored as a result of repeated exposures to those stimuli, leading to predictions as to what types of stimuli would be more readily identified by the central pitch processor. In music, for example, the three tonal components of a major triad stand in a 4:5:6 frequency ratio, and imply a fundamental two octaves below the root of the chord. In comparison, the components of a minor triad stand in a 10:12:15 frequency ratio, a seemingly more difficult pattern of relationships to detect for derivation of a fundamental. A likely perceptual outcome would therefore be that the major triad would provide a much stronger tonal center than the minor triad.

Terhardt's model has one further ramification regarding the perceptual responses predicted on the basis of music-theoretic principles. According to Terhardt, determination of virtual pitch is based on a process that is not merely reflective of the practices of a particular musical culture or style. Rather, its determination comes about as a result of some basic psychoacoustic processes used to analyze complex acoustic signals, especially speech signals (see Terhardt, 1984). In this way, music-theoretic principles of harmony may be describing a basic biological response to complex signals, a response which could have existed long before the evolution of organized music. With respect to the present thesis, this would lead to the expectation that fundamental/root perception in chords should be a fairly strong phenomenon. Also, because of the belief that this response is one which can be modified through learning, it might also be expected that those with more training (i.e., musical training) would be able to identify a fundamental or root more easily than those with less formal experience in the system. Terhardt himself, however, claims that language training is sufficient for learning the harmonic relationships that imply certain virtual pitches. Finally, it raises the possibility that music-theoretic rules may be more than descriptors of musical practice, but may be reflective of some basic perceptual-organizational principles.

Inversion Equivalence

A controversial aspect of major triads concerns the supposed harmonic equivalence between the different positions or inversions in which a triad can be voiced. Inversions are simply rearrangements in the pitch order of the three notes comprising the triad. If the lowest tone is a root (i.e., one of the scale degrees), such that the intervals of a third and a fifth occur above that root, then the triad is said to be in root position. Theoretically, this position is considered the most stable. If the third is the lowest tone such that the intervals of a third and a sixth occur above it, the triad is said to be in first inversion. Going one step further, if the fifth is the lowest tone with the intervals of a fourth and a sixth above it, the chord is in second inversion. The first inversion is considered less stable than the root, and the second inversion is considered less stable than the first inversion and root (Ratner, 1962).

Forte (1979) expressed the music-theoretic functions of the first and second inversions in relationship to the root. "The 6th chord [first inversion] is regarded as equivalent to the [root] from which it is generated (p. 72)....The 6th chord often occurs without its parent chord [root] and serves not as an extension but as a representative. In this capacity it fulfills much the same function as would the parent chord in the same context" (p. 75). In contrast, the music-theoretic notion is that the second inversion is not equivalent to the root chord. The rationale for this claim is based on the concept of consonance and dissonance of the component intervals which combine to form a triad. When all intervals that can be formed between the three notes of a triad are considered to be consonant, then the chord itself is considered consonant. The root and first inversion are therefore consonant chords because of the presence of consonant thirds, fifths, and sixths. Because the interval of a fourth is considered dissonant and is contained within a second inversion, all second inversion chords are considered dissonant (see also Goldman, 1965; Piston, 1978; Randel, 1978). In this way, a dissonant second inversion could not be considered equivalent to a consonant root (Forte, 1979; Kohs, 1961). Forte does, however, indicate one instance in which the second inversion is regarded as an extension of the root, and this occurs whenever it is positioned immediately after the root. In this case the second inversion is not considered dissonant, because the fourth does not demand resolution to a third (as is needed in other presentations of the second inversion). Such an argument assumes that musical triad perception can be accounted for by an analysis of the component intervals of a triad, and furthermore, assumes that the processing of musical stimuli is dependent upon the musical context in which those stimuli are heard.

An alternative viewpoint, expressed in the eighteenth century by Rameau (1722/1971), is that all three triad positions are equivalent because they are simply presentations of the same three notes voiced in different octaves. Furthermore, these three notes taken together imply the same fundamental, or basse fundamentale, a note two octaves below the root of the chord. Because of Rameau's acceptance of octave equivalence, the root would essentially be identical to the fundamental occurring two octaves below the root of the triad, the same fundamental implicated in the missing fundamental phenomenon, and Rameau therefore referred to the root itself as the basse fundamentale. It was Rameau's contention that notes possessing the same letter names but occurring in different octaves, were not merely extensions of one another, through the doubling or halving of frequency, but were instead irrefutable "replicates." In his arguments he appealed to resonance experiments in which a string vibrating at a certain frequency in the presence of an initially stationary string an octave higher or lower, resulted in the vibration of that initially stationary string. Rameau interpreted this finding as a demonstration of the strong relationships between octaves. He also stressed the importance of the fundamental, or first mode of vibration, to the identity of a sound, claiming that without the presence of the fundamental, or even an implied fundamental, the chord was "destroyed." The necessity of this fundamental, and of the assumption of octave equivalence to inversion equivalence is expressed in his Traite de l'harmonie (1722/1971):

> "Since harmonic ratios offer us only the perfect chord [root],...we cannot allow the sixth chord [first inversion] and the six-four chord [second inversion] derived from it without assuming that the fundamental sound of this perfect chord is implied in its octave; otherwise the source would be completely destroyed. Experience, in addition, which makes us feel that a chord consisting of the third and fifth is always perfect and complete without the octave, still permits us to consider this octave implied, since it is the first interval generated. When this octave is then

> placed above the third and fifth, with which it thus forms a sixth and a fourth, it continues to produce an acceptable chord, even though the fundamental sound is no longer present. The fundamental sound is transposed or implied in its octave, and therefore this last chord is less perfect than the first, although it is made up of the same sounds. These different expressions: 'the source is inverted, it is merged, transposed, or implied in its octave,' are all basically the same; thus, the upper sound of the octave should in no way be regarded as a source different from that by which it was directly generated. Instead, this upper octave represents the source and makes with it an entity in which all sounds, all intervals, and all chords should begin and end. It must not be forgotten, however, that all properties of this octave, of sounds in general, of intervals, and of chords rest finally on the single, fundamental source, which is represented by the undivided string or by the unit." (p. 12-13)

Terhardt (1984) provided a demonstration of the compelling nature of the fundamental bass to which Rameau appealed. He presented several sequences of chords, each implying an identical sequence of fundamentals, but the sequences differed with respect to the inversions in which the triads were voiced. Whether the sequences contained triads all presented in the same inversion, or in a variety of inversions, the resultant perception was one of the same sequence of fundamental notes being played.

Arguments of octave equivalence and fundamental/root perception support the expectation in the present thesis that roots, first inversions, and second inversions will be regarded as perceptually equivalent. If, however, Forte (1979) is correct in his proclamation that the second inversion is only considered equivalent to the root under circumstances where it immediately succeeds root presentation, then notions of inversion equivalence will have to be extended to include a contextual component. That is, the three positions in which a triad can be voiced are only equivalent when presented in particular arrangements, with these contextual cues perhaps overriding the influence of fundamental perception and octave equivalence.

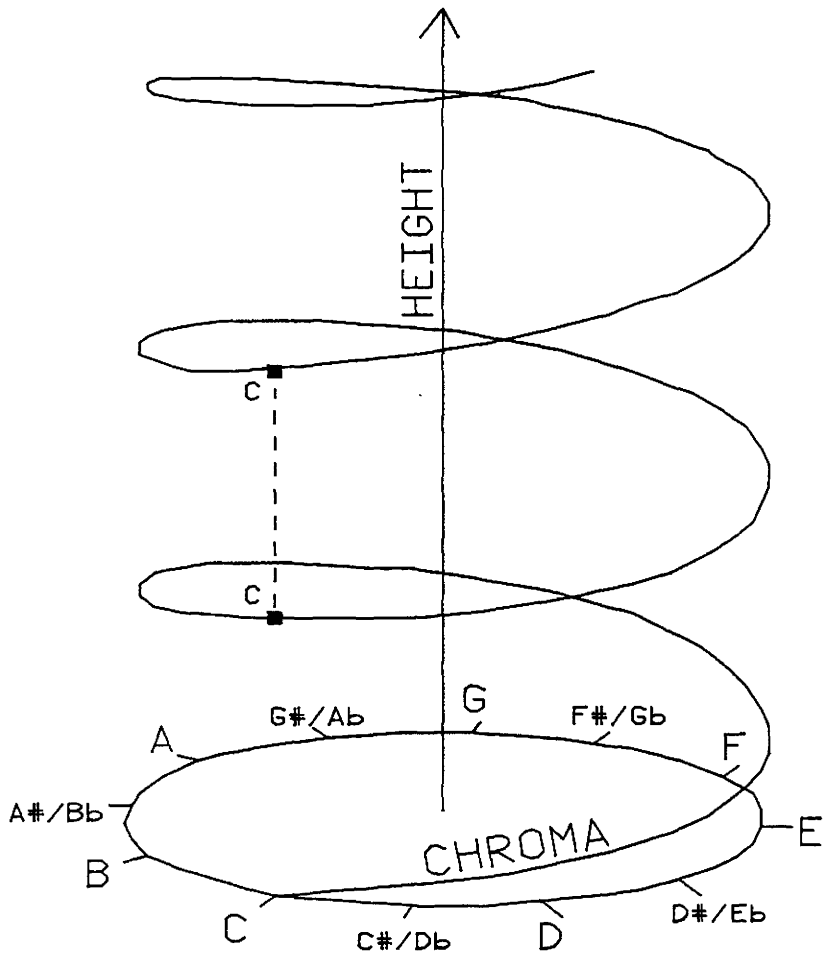
Tone-Height and Tone-Chroma

In both present-day and eighteenth century music theory (Forte, 1979; Rameau, 1722/1971) is the acknowledgement that triads voiced in different positions sound similar to some extent. This is evidenced by the substitutability that often occurs between the inversions in musical compositions. At the same time, however, there is something very different about the sounds of these chords. After all, when any two tones are the distance of an octave apart, one tone will be twice the frequency of the other, giving the impression of a tone higher in pitch than its octave counterpart. Even Rameau, who was perhaps most stringent in his claims of inversion equivalence, admitted that one inversion might be used in place of another to create a sense of "diversity." These two aspects of chord perception, the same and different qualities experienced by a listener, have been expressed as tone-chroma and tone-height (Bachem, 1950). Tone-chroma refers to the location of the tone within the octave and tone-height refers to the absolute frequency of the tone. In musical notation, tones possessing the same chroma share the same letter name. For example, A_1, A_2, and A_3 are all of the same tone chroma, but each occurs in a different octave. Each of these notes also has a unique frequency associated with it, corresponding to its tone-height, such that the progression from A_1, to A_2, to A_3 is associated with an increase in pitch-height.

Early research recognized the existence of these differential tone qualities, and attempted to represent them in a geometric space. Drobisch (1846, 1855, cited in Ruckmick, 1929) was probably one of the first to depict the similarity of tones the distance of an octave apart by placing them directly above and below one another on a spiral representing pitch relationships. Ruckmick (1929) built on this concept by devising a "tonal bell." Octave relationships were shown directly above and below one another on a spiral, and tone-height relationships could be followed by tracing the progression of tones from lower to higher portions of the spiral. Ruckmick also felt it necessary to capture the difficulty with which tone discriminations were made at both the low and high ends of the frequency range, relative to frequencies in the mid-range. This was done by separating successive turns of the spiral by a greater amount at mid-range frequencies in comparison to turns representing low and high frequencies. Musical interval relationships were indicated by lines drawn across the spiral to join the tones which were combined to form them.

Shepard (1982) discussed his 1965 helical configuration of the multidimensional nature of tone perception (see Figure 9). In this form, tone-height is represented by travelling from lower to higher positions along the spiral, with tones higher in frequency occuring toward the top of the spiral. Tone-chroma is displayed by a helix wrapping around an imaginary vertical axis in such a way that tones a semitone distance apart from one another are adjacent on the spiral, and tones an octave apart fall directly above and below one another. Other researchers have empirically derived geometric representations of pitch perception through multidimensional scaling analyses to depict tonal relationships other than height and chroma. For example, Krumhansl (1979) obtained a conical solution representing the relationships between major triad components and other diatonic tones, relationships

Figure 9. A simplified version of Shepard's (1965) helical representation of the mutidimensional nature of tone perception.


HEIGHT
C
C
A
G#/Ab
G
F#/Gb
F
A#/Bb
E
CHROMA
B
D#/Eb
C
C#/Db
D

between diatonic tones and nondiatonic tones, and relationships between tones of different pitch-heights. Krumhansl and Kessler (1982) showed the relationships between major, minor, and relative and parallel major and minor keys[2] on the surface of a torus.

That the pitch-height dimension of tones can be easily attended to is well documented, and seems to be an especially salient feature of tone perception among less-musically-trained listeners (Allen, 1967; Kallman, 1982; Krumhansl & Shepard, 1979; Sergeant, 1983). That is, when musically-inexperienced subjects are asked to make similarity judgements between successive tones, their results generally reflect judgements made on the basis of absolute frequency similarity rather than chroma similarity. In this way, the note C_4 (played at 261.6 Hz) and the note D_4 (played at 293.7 Hz) would be judged as sounding more similar to one another than two tones an octave apart (e.g., C_4 played at 261.6 Hz, and C_5 played at 523.3 Hz).

Tone-chroma is a more cumbersome tone characteristic to describe, and it is not clear what its relationship is with musical training. The perception of chroma is closely tied with the theoretical axiom of octave equivalence, in which notes that are an interval of one or ;more octaves from each other are considered to be harmonically equivalent (Forte, 1979). Octave equivalence refers to the impression that all A's or all E's, for example, have an A-quality or E-quality, respectively. Recall also that octave equivalence is one of the assumptions on which Rameau based his claims of inversion equivalence.

One study of octave equivalence was conducted by Allen (1967), who investigated the perceived similarity of tones an octave apart. He instructed both music majors and musically-untrained subjects to rate the perceived similarities of pairs of tones on a 7-point scale. Results showed that only the musically-experienced subjects rated tones which were the distance of an octave apart as sounding very similar, whereas the musically-untrained subjects judged two tones as similar if their frequency separation from one another was not as distant as for another pair of tones.

Kallman (1982) also had subjects rate how similar two tones sounded, by presenting 19 different tones spaced between 0 and 28 semitones apart. Regardless of subjects' musical experience, all tended to judge two tones as similar if their absolute frequencies were similar. He conjectured that a musical context was necessary in the evocation of octave judgements, and proceeded to present undistorted and distorted melodies for comparison. The distorted versions had the third or fourth note played a variable number of semitones from the correct note in the undistorted version. If octave equivalence was to be observed between the two versions of the melody, it would be expected that melodies in which the notes were displaced by an octave would be rated as sounding very similar to the undistorted melodies. Results showed, however, that subjects continued to judge the two melodies on the basis of frequency distance between them: those with notes displaced further from the undistorted version were judged as less similar to one another. Finally, Kallman proposed that by decreasing the tone-height differences between his stimuli, he might be able to decrease the saliency of this dimension, and thereby increase the saliency of tone-chroma. He therefore presented tones which ranged from 10-14 semitones, in both the isolated tone comparison test and the melodies test. Unfortunately, when he decreased the range over which the absolute frequencies of tones were presented, he also decreased the number of levels of stimuli from 19 to 9. His results indicated some degree of octave generalization, although one cannot be sure whether the result stemmed from the narrower range of frequencies presented, or lower number of stimuli to be compared. Furthermore, the incongruency of this result with that of Allen (1967), who observed octave equivalence for 23 levels of stimuli ranging from 225 Hz to 4800 Hz, is puzzling. It was perhaps the higher level of training achieved by Allen's subjects (music majors) in comparison to Kallman's (his most-highly-trained subjects had a minimum of five years training), that resulted in their ability to judge octaves as similar. (Although Kallman did test three graduate music majors with his set of 19 stimuli, only one of these subjects demonstrated sensitivity to octaves. With only three subjects tested, however, a conclusion here would be premature.) One final difference between the two studies involved Allen's use of a constant standard against which to judge the comparison tones, compared to Kallman's use of a variable standard. Perhaps a constant standard made such tonal judgements easier, and thus the expected octave equivalence was observed in the Allen study.

The discrepant conclusions made with regard to empirical investigations into the concept of octave equivalence is not limited to differences obtained between groups of musically-trained and untrained subjects. Ward (1954) found that, within a highly-trained population, subjects asked to adjust a variable tone to be an octave distance from a standard displayed large intersubject variability between their settings, intrasubject variability between days of testing, intrasubject variability between ears tested, and decreased accuracy in settings at high frequencies. Furthermore, Thurlow and Erchul (1977) found that the ability to "conceptualize an octave" was not limited to those with musical training, nor was it pervasive within the musically-experienced population they observed. When they tested subjects who had enough musical training to be able to name musical intervals presented within an octave, they found that only some of these subjects were also able to identify intervals presented at a span greater than an octave. Within these few subjects, octave equivalence was apparently a compelling phenomenon. When another group of subjects, who possessed the ability to identify musical intervals, was tested for their ability to adjust a variable tone to be the distance of an octave from a standard tone, only some subjects could adjust upward to make the match, while none were able to reliably adjust a tone downward. This was taken as an indication that subjects may be making interval matches when tuning their instruments upward, which is the common practice, and not chroma matches. Finally, when a group of untrained subjects was tested, it was found that they had much difficulty in adjusting a tone pulse with a continuously variable frequency to be an octave interval from a stationary tone, but 6 of 11 subjects could choose the two tones that were an octave distance apart, when given a choice between an octave and a non-octave comparison.

A further way to test for the existence of octave equivalence would be to study lower animals, in which the phenomenon might occur naturally, without prior exposure to music or speech. Blackwell and Schlosberg (1943) measured the amount of generalization shown by white rats to tones an octave apart. One group of rats was taught to respond to tones of 10,000 Hz, 8,000 Hz, 7,000 Hz, 5,000 Hz, and 3,000 Hz. A punishment procedure was then used to extinguish responding to all tones except the one presented at 10,000 Hz. During the test phase, using all the orginal tones, results were indicative that tones an octave apart were treated in a similar manner. That is, both in terms of response frequency and log latency to respond, the rats' responding indicated generalization between the 5,000 Hz and 10,000 Hz tones. This group of rats appeared to have perceived something very much the same about tones an octave apart, in comparison to tones at intervallic distances other than an octave. Another group of rats, however, did not demonstrate octave generalization. This group was taught to respond during silence, but was punished when responding to a 10,000 Hz tone. Upon testing with 10,000 Hz, 8,000 Hz, 7,000 Hz, 6,000 Hz, and 5,000 Hz tones, the rats responded to all but the 10,000 Hz tone. The authors claimed that this group showed such great discrimination that they did not exhibit generalization to the 5000 Hz tone. It would appear that it is as difficult to predict the circumstances under which the phenomenon of octave equivalence will be obtained in infrahuman subjects, as it is in humans.

There exists a population of individuals who possess absolute pitch, or the ability to give the letter name to a tone played in the absence of any other musical context. Although it is controversial as to whether this ability is acquired or inborn, there is support for its existence (Bachem, 1954; Brady, 1970; Cuddy, 1970; Ward & Burns, 1982). One might expect that subjects with absolute pitch would be able to identify both the note name and octave of a tone presented to them, but Bachem (1954) observed that a subject with absolute pitch could identify the letter name of the note presented, but had difficulty identifying the octave from which it was drawn. Ward and Burns (1982) also acknowledged the existence of octave errors made by absolute pitch subjects, in their discussion of how such errors should be handled during data analysis. Apparently, these absolute pitch subjects were sensitive to the similarity of tone chroma for tones which are an octave apart, and this ability superseded the ability to determine tone height (or the octave from which the tones were drawn).

Studies investigating the perceived equivalence of musical intervals, or dyads, provide some indirect support for the existence of octave equivalence. Plomp, Wagenaar, and Mimpen (1973) required music students to identify musical intervals, and found tendencies for confusions to occur between intervals that were inversions of one another. These confusions were most pronounced between fourths and fifths, and between seconds and sevenths, with some confusion also observed between thirds and sixths. If octave equivalence was an especially compelling phenomenon for these music students, then perhaps these inversion errors were a result of mistaking the octave in which each note of the interval was located. Killam, Lorton, and Schubert (1975) also tested music students' ability to identify musical intervals. They found that inversion errors did not comprise a substantial proportion of the types of errors made, but when they did occur, they were most prominent between fourths and fifths.

It is evident from these studies on the bidimensional nature of pitch, that pitch renders at least two qualities to which subjects can attend and make judgements. It would seem reasonable that these two dimensions of height and chroma could be extended to judgements of musical triads. Furthermore, if the argument that the phenomenon of octave equivalence is responsible for the equivalence of triad inversions, then these demonstrations of octave equivalence could be taken as necessary prerequisites to show inversion equivalence. It might also be expected that differences in the relative salience of these two dimensions are related to an individual's musical background, with musically-experienced and inexperienced subjects finding tone-chroma and tone-height to be more salient characteristics, respectively. This relationship to experience is not a clear one, however, since even animals that would not be expected to have any musical background have been shown to perceive a certain similarity between tones an octave apart under certain circumstances. Furthermore, observations of octave equivalence appear at least somewhat dependent on the methods used to study it. Finally, given the literature on interval identification, in which confusions were evident between inverted intervals, it might also be the case that triads voiced in different positions would also be treated as very similar to one another.

Tonal Hierarchies Involving the Triadic Tones

There have been studies which have attempted to elucidate the theoretical internal representations of the tones upon which chords are built. Krumhansl and Shepard (1979) developed a "tone-probe method" to empirically test for the presence of this presumably well-structured representation. The procedure involves the presentation of some form of musical context followed by either one tone to be rated for degree of similarity to the preceding context, or two tones to be rated for degree of similarity to each other in the presence of that context. In the Krumhansl and Shepard (1979) study, subjects were presented with either an ascending or descending major scale, such that the eighth tone (final tone) of the scale was absent. On each trial one tone from the chromatic scale was placed in the eighth position, and subjects rated how well the eighth tone completed the scale. Results showed all subjects to rate the scale tones as better completers of the context than nonscale tones. Furthermore, within the set of scale tones, the tonic received the highest ratings. There was an effect of musical experience, with the subjects possessing more extensive musical training showing the highest ratings for the scale tones. Within the set of scale tones, these more highly-trained subjects also showed differential preferences among the tones, indicating the tonic to be most significant regardless of the octave in which it was presented (evidence for octave equivalence), followed by the fifth, and then the third. An effect of pitch-height was also evident for these subjects, as shown by elevated ratings for the second and seventh scale degrees, tones which were closest in pitch-height to the ascending and descending scale contexts. The subjects with the least amount of musical training were especially influenced by pitch-height factors, in that they were inclined to rate tones close in absolute frequency to the context sequence as good completers of the sequence. The authors concluded that the most-experienced subjects had developed a tonal hierarchy in which octave equivalence predominated over pitch-height, and in which the tonic, followed by the fifth, and then third scale degrees held more significance than the other diatonic tones. Nondiatonic tones were perceived as the least satisfactory of all possible scale completers.

Krumhansl (1979) further investigated the proposed hierarchical structure, exploiting Rosch's (1975) suggestion of the existence of "cognitive reference points." In Rosch's experiments, it was found that within the non-musical domains of color, line orientation, and number, that focal colors, vertical, horizontal, and diagonal lines, and multiples of ten served as prototypes, or reference points. That is, nonprototypical entities within the category could be ordered in terms of good and poor examples of the prototype. Furthermore, when subjects were given the opportunity to judge alleged prototypes in reference to nonprototypes, or to judge nonprototypes in reference to the prototypes, subjects chose the second relationship, indicating that directionality of their judgements was important to perceiving the prototypes as standards to which "sub-standard" items could be compared. Krumhansl (1979) suggested that a similar type asymmetry in judgment might exist for tones, such that certain tones might serve as prototypes to which all others are compared. By utilizing the probe-tone technique, she presented musically-experienced subjects with either the context of a major triad or an ascending or descending major scale. Subjects were then presented with two comparison tones to which they had to judge how closely related the first tone was to the second tone. The resultant ratings did not differ between contexts, and they reflected the predicted asymmetrical ratings. That is, tones considered less related to the tonality were often rated as sounding very similar to tones considered more strongly associated with the tonality, but there was not a tendency for tones considered more characteristic of the tonality to be judged as similar to "weaker" tones. For example, a diatonic tone not included in the major triad compared to a tone in the triad received very high ratings. A nondiatonic tone compared to a diatonic tone not in the major triad also received high ratings, as did a nondiatonic tone compared to a major triad tone. The absolute pitch-height of the tones was found to influence similarity ratings, but this was most evident for the nondiatonic tones.

To determine if those tones deemed less stable in a music theory sense were also less stable in the internal representation, Krumhansl (1979) employed a recognition memory task. She presented a standard and a comparison tone separated by a sequence of tones, and had musically-experienced subjects say whether or not the standard and comparison tones were the same. She proposed that tonal sequences might enhance the memorial representation of diatonic tones, while concomitantly weakening that of nondiatonic tones. Her results showed that memory for diatonic tones was better in tonal than atonal contexts. Also, within a tonal context, as compared to an atonal context, subjects were more likely to confuse nondiatonic tones with diatonic tones than the opposite order, once again supporting perception of the prototypical nature of diatonic tones.

The experiments thus far discussed have involved only adult listeners, but Krumhansl and Keil (1982) attempted to determine when the tonal hierarchy was established in children. They presented melodies consisting of the components of a major triad, followed by two tones, to children in grades 1-6 and a group of adults. Subjects then had to rate the goodness of completion of these two tones. Results showed that with increasing age there was a greater separation between ratings of nondiatonic and diatonic endings. In particular, there was an increasing preference for endings consisting of two tonic tones, two tonic triad tones, and two tones of which the first was a non-triadic diatonic tone and the second was a tone in the triad. The foundations of the tonal hierarchy appear to have been established in the youngest group of children, as reflected in their ability to differentiate diatonic and nondiatonic tones. Children in grades 3-4 gave even higher ratings for triad tones than for non-triad diatonic tones. None of the children showed a preference for tonics an octave apart over other triad tones, but the adults perceived these two tones as very good completers of the melodies. It seemed that the children were guided more by pitch-height, whereas the adults (mean years of musical training = 7.8) demonstrated octave equivalence.

Acquisition of a tonal hierarchy as a function of experience has also been demonstrated in the music of other cultures. Castellano, Bharucha, and Krumhansl (1984) showed that ratings of tones drawn from North Indian music were highest for the tonic, fifth, and vadi (the most frequently stressed tone, excluding the tonic and fifth, in terms of duration, accent, and frequency of occurrence, but theorists are unclear as to how this tone is selected and what its intervallic relationship is to the other scale tones). Although both Western and Indian listeners appeared sensitive to these internal structures, the Western listeners seemed to base their judgements on relative tone durations, whereas Indian listeners also used scale membership to make their decisions.

It is apparent in these studies investigating the existence of a tonal hierarchy, that provision of a musical context was sufficient to induce differential ratings of tones in a manner predicted by music theory. In particular, preferences declined in order of the tonic, fifth, and third scale degrees, which combine to form the major triad, followed by other diatonic tones, and then nondiatonic tones. Sensitivity to the tonal hierarchy appeared most prevalent among musically-experienced subjects, with reliance on pitch-height predominating the judgements of the less-musically-trained individuals.

Chordal Hierarchies Involving Relationships Between Major Triads

The demonstrations of an organized system of tonal functions led Krumhansl and her colleagues to conduct a series of investigations into the music-theoretic system of chordal relationships, and these studies have resulted in evidence supporting a highly structured organization of chordal functions. This organization has been shown to operate at the level of chord relationships within a key, reflecting such aspects as the differential importance of chords built on various scale degrees; and also at the level of relationships between chords of different keys, resulting in a structuring indicative of the Circle of Fifths. In the five experiments discussed below, all chordal and tonal stimuli were constructed in the manner described by Shepard (1964) such that pitch-height and inversion effects were attenuated. Shepard's method involves inclusion of the sinusoidal frequency components of chords (or tones) over several octaves, with the loudness levels of the components kept constant over the center range, and tapered off to threshold at the highest and lowest frequencies (see, for example, Figure 11). The result is a chord with no clearly identifiable highest or lowest pitch (although chords comprised of different tones will vary with respect to the highest or lowest tone represented under the envelope), or a tone with a rich organ-like quality. The subjects employed in these five studies all had a moderate degree of musical training, and in all studies in which at least some of the subjects possessed a certain amount of theory training, no differences were found between the results of those who had this background and those who did not.

Krumhansl, Bharucha, and Kessler (1982) used a variation of the tone probe method to obtain similarity ratings for different types of chords. Two chords were chosen from among major, minor, augmented, and diminished chords of three highly related keys (C major, G major, and A minor), and were presented after a context scale in each of these three keys. Subjects were asked to rate how well the second chord followed the first in relation to the scale. Results showed that ratings were somewhat lower when the first chord was major and the second was either minor, diminished, or augmented than when the major chord appeared in the second position. It was suggested that this provided support for theoretical notions of the perceived importance of the major triad. There was also a tendency for high similarity ratings to be obtained when both chords were of the same key as the context scale. This result, along with the extremely low correlation between the pitch-heights of the two chords and obtained similarity ratings, were taken as evidence that the chords contructed by Shepard's (1964) method decreased the salience of the overall pitch-height of the chords, and in effect, helped to establish a strong sense of key. Another result showed the correlations between the chords built on the same scale degrees to be similar between all three keys, and this was taken as an indication that subjects were sensitive to chord functions within a key, for example, I, IV, or V chord functions. When the ratings were averaged across all three keys and subjected to a multidimensional scaling analysis, a configuration emerged depicting a central clustering of the I, IV, and V chords, with chords less central to the tonality scattered around this cluster. Hierarchical clustering on these same data revealed a joining of the I and V chords, followed in succession by the IV, VI, II, III, and VII chords. This ordering supported the theoretical functioning of these chords within a tonality, with those more central to the tonality being joined before those not considered as strong.

Krumhansl, Bharucha, and Castellano (1982) investigated the perceived relationships between two maximally-distant keys, C and F# major, by having subjects rate how well chords in these two keys followed one another in the presence of a cadence played in the key of G, A, or B major. The obtained ratings, when analyzed through a multidimensional scaling program, showed that the contextual key established by the cadences affected which chords were perceived to follow each other best: chords more closely related in a musical sense to the contextual key were given higher ratings, and when the two chords were drawn from the two maximally-distant keys, preferences were shown for endings on a chord more musically related to the context. This result followed a predictable pattern, as described by the Circle of Fifths, in that as distance between the keys of the context and the chords became greater, ratings decreased. The results also indicated that regardless of the established context, within each key there was a differentiation of chordal function which supported predictions made by music theory. Hierarchical clustering performed on data averaged over the three context types for the C- and F#-major chords showed the most musically stable I, V, and IV chords to cluster first, followed by the VI, II, VII, and III chords. Results also revealed preferences for chord pairs ending on the I, IV, or V chords, further establishing the perceived importance of these chords.

In a second experiment, Krumhansl et al. (1982) presented subjects with a same/different discrimination task involving two seven-chord sequences. The sequences were constructed in such a way as to strongly imply a context of C, G, A, or B major. In the fourth serial position of each sequence was inserted a C- or F#-major chord, depending on the condition under test: (1) the same C- or F#-major chord appeared in both sequences; (2) a different C-major chord appeared in each sequence; (3) a different F#-major chord appeared in each sequence; (4) a C-major chord was presented in the first sequence with an F#-major chord in the second sequence; (5) an F#-major chord was presented in the first sequence with a C-major chord in the second sequence. Results showed that subjects' patterns of responding once again followed a Circle of Fifths ordering, such that subjects' responses on trials in which the sequences were identical were more correct when key distance between the context and target chords were closer. On trials in which a chord was changed to another chord in the same key, errors increased as musical relatedness between the keys of the context and target chords increased. On trials in which the changed chord was drawn from a different key, the error rate increased as musical relatedness between the keys of the context and the second target chord increased.

Similar to the Krumhansl et al. (1982) experiment, was one conducted by Bharucha and Krumhansl (1983) in which they presented chords from the maximally-distant keys of C and F# major, and asked subjects to rate how well the second chord followed the first. On some trials, a context was established through presentation of a cadence in either C or F# major, and on other trials, no preceding context was presented. A multidimensional scaling analysis revealed that on trials where no cadences were presented prior to the two comparison chords, subjects made a clear separation between chords drawn from C major and F# major. When a C-major cadence was presented, the resultant scaling showed the C-major comparison chords to be clustered very close to one another, while at the same time separated from the more scattered F#-major comparison chords. With the presentation of an F#-major context, the opposite result occurred. On trials where a cadence was presented and chords were presented from both C and F# major, preferences were shown for chords ending in the key established by the cadence. Regardless of whether or not a prior context was presented, the I, IV, and V chords within each key were joined in a compact cluster, surrounded by the other chords considered less central to the tonality. Hierarchical clustering for data averaged over all experimental conditions showed a clustering of the I and V chords, then the IV chord, followed by the VI and II chords, and finally the VII and III chords.

In a same/different discrimination task, Bharucha and Krumhansl (1983) presented subjects with two seven-chord sequences comprised of either chords selected randomly from different keys, or selected from one key. A changed target chord between the two sequences could be a chord selected either from within or outside the contextual key. Results supported three principles of chordal relationships. The first principle predicted that if a chord is presented which is drawn from the established key, its representation in memory will be more stable than if a nondiatonic chord is presented or a random context is established. Subjects were better at identifying when two diatonic sequences were the same than when both sequences were random, or when both were diatonic with a nondiatonic chord in the target position. The second principle predicted that the more alike two items were, the higher the probability of difficulty in differentiating between them. This was supported in the finding that performance was best for nondiatonic targets changed to other nondiatonic targets in a tonal context. Next best performance was found in the random context condition, in which random targets in a random context were changed to other random targets, followed by the condition in which diatonic targets were changed to other diatonic targets in a tonal context. The third principle claimed that chords not within the contextual key would be more likely to be confused with chords within the key than it would be that chords within the key would be confused with those outside. Within a tonal context, subjects made more errors when attempting to identify when a nondiatonic chord was changed to a diatonic chord than when a diatonic chord was changed to a nondiatonic chord. Here again was a demonstration that the theoretically more stable elements serve as prototypes to which less stable elements are compared.

In an attempt to determine in more detail the characteristics of diatonic and nondiatonic chords leading to memory facilitation or disruption, Krumhansl and Castellano (1983) presented two eight-chord sequences and had subjects identify which chord in the second sequence had been changed. The sequences were constructed of chords drawn from the key of C major, with changed chords also selected from the key of C major. On some trials, these C major sequences also contained one nondiatonic chord, selected from either the key of A major or F# major. The results showed that subjects' identification performance decreased when the sequence contained a chord that was nondiatonic in C major. In particular, subjects often identified the nondiatonic chord as the changed chord (although this was never the case), and performance got worse as key distance of the nondiatonic chord from the key of C major became greater. To the extent that a sequence did not conform to subjects' expectations of proper key elements, their errors in identifying the nondiatonic chord and chords presented in close temporal proximity to this chord as the changed chord increased. This experiment provided more evidence that relationships between musical keys can be described in terms of key distance on the Circle of Fifths.

Krumhansl and Kessler (1982) also obtained support for a representation of keys organized by key distance. They had subjects perform a rating task of how well each of the 12 chromatic tones followed major and minor scales, chords, and cadences. A multidimensional scaling analysis of the ratings resulted in a four-dimensional solution, in which the first two dimensions represented the relationships between major and minor keys, as predicted by the Circle of Fifths. The third and fourth dimensions reflected the parallel minor and relative minor keys on either side of their respective major keys, with the parallel major and relative major keys also on either side of their respective minor keys. The four-dimensional solution was represented by the authors on the surface of a torus to depict these musical key relationships.

Krumhansl and Kessler (1982) also investigated how the sense of key developed within a musical context by presenting successively more chords, from 1-9, and having subjects rate each of the 12 chromatic tones after the presented context. They found that in the nonmodulating sequences the correlations between key profiles from which the chords were selected and the ratings of tones increased as the number of chords presented increased, indicating that a sense of key evolved with the number of chords played. It is important to note, however, that these correlations were not perfect with respect to the key which was intended to be produced by the sequence, indicating that individual chords were exerting some influence as to how strongly they themselves, regardless of their relationships to the other chords in the sequence, were interpreted in relation to the intended key. Further, if a modulation occurred in a sequence, and the modulation was to a closely-related key, ratings indicated that the sense of the first key remained, but the ratings became more and more similar to the profile expected for the new key. For distant-key modulations, however, the sense of the first key was lost by the end of the sequence, and it also took longer to establish the sense of the new key. It would seem then that once a key is instantiated, it sets up expectations for close modulations, which by convention are the most likely to occur, and does not lend itself easily to the possibility of a distant modulation.

Another study which investigated the internal representation of triads was conducted by Roberts and Shaw (1984). It differed from the previously mentioned studies of Krumhansl and her colleagues in that no context ever preceded chord judgements, and chord position (root and first inversion) was one of their manipulations. They presented pairs of chords which were either both in root position or first inversion, and had subjects judge whether or not both chords were of the same or different type (major, minor, augmented, or diminished). The results showed that only the highly-trained subjects (those with some piano training, at least 2 years theory, and at least 10 years lessons on an instrument) gave results with an interpretable pattern. This highly-trained group showed a "key-distance effect" in that discrimination performance was best for triads whose roots were an octave apart, with discriminations becoming worse as key distance between the two chords became greater. The pattern resulted mostly from major/major and minor/minor pairings, and the authors took this finding to be indicative of the strong tonal centers associated with major and minor triads. A similar Circle of Fifths ordering was not found when comparing different chord types. Another particularly pertinent finding with respect to the present work was that although subjects were superior at discriminations of root chords as compared to first inversions, their patterns of discrimination were very similar for both chord positions. Roberts and Shaw interpreted this finding in terms of a recoding from the first inversion to the root position. They suggested that with increasing musical experience one develops internal representations of major, minor, augmented, and diminished chords which exist in root position, with interpretation of chord inversion taking place as a result of recoding into the represented root form.

In a subsequent similarity rating task, Roberts and Shaw (1984) found that highly-trained subjects rated roots and first inversions of the same chord type as sounding very similar to one another. Moderately-trained subjects, however, based their judgments on the pitch-height of the chords.

Conclusions to be Drawn From Empirical Investigations of Chordal Hierarchies

These empirical investigations into chordal hierarchies produced several results pertinent to the present thesis. One of these was empirical support found for the strong key-defining characteristics of major triads. This is important to the present work if evidence is to be gained for major triads establishing a strong sense of key in the absence of more elaborate musical context, such as scales or melodies.

Another finding of these studies, that chords were perceived as similar to the extent that they were drawn from closely-related keys, and that similarity judgements followed an orderly pattern corresponding to the Circle of Fifths, is also relevant to the present work. Although in the majority of these chordal hierarchy studies a strong key-defining context was presented prior to chord judgement, if the major triad in isolation is capable of being perceived as a stong key-defining unit, then it might be expected in the present work, where only isolated triads are to be presented, that an orderly pattern of judgements following the Circle of Fifths will also emerge.

Furthermore, the support provided in these studies for a highly-organized hierarchy of chordal functions within keys, with the I, IV, and V chords forming a stable harmonic core, is also essential to the present work. In the present thesis, the existence of relationships between chords based on the

Circle of Fifths is to be tested, an organization which can be regarded as a progression from a I chord to a V chord, as one moves clockwise around the circle. Alternatively, the progression can be viewed as a movement from a I chord to a IV chord, as one moves counterclockwise around the circle. Evidence that these I, IV, and V chords are strong, stable entities within their respective keys lends credence to the expectation that a perceptual organization could possibly be represented in this way.

Finally, the Roberts and Shaw (1984) study provided some indirect support for the equivalence of roots and first inversions. Such a hypothesis will be directly tested in the present thesis, along with the proposal of an equivalence of these two chordal positions with second inversions. Furthermore, Roberts and Shaw found some support that sensitivity to these highly structured chordal relationships was present only in very highly-trained musicians, whereas moderately-trained musicians relied on pitch-height. That Krumhansl and her colleagues could obtain evidence for these structures among moderately-trained subjects is perhaps due to their presentations of strong key-defining contexts prior to the musical material to be judged. In one experiment in which no context was used (Bharucha and Krumhansl, 1983), subjects were tested with chords from two maximally-distant keys, which may have sounded so different to the subjects, that no additional musical cues were necessary. Roberts and Shaw, on the other hand, presented no musical context beyond the triads themselves, and they used six chords spanning the Circle of Fifths.

THESIS OBJECTIVES

The five experiments of the present thesis examined several theoretical assumptions concerning the perception of major tonic triads.

The first of these concerned the supposed equivalence between the three positions in which a triad can be voiced. One way in which subjects could judge the similarity of inversions would be by perceiving the occurrence of a common tone-chroma in each of the chords. Root position, first inversion, and second inversion triads built on the same root-note also share the same third and fifth. These chords could therefore be perceived as equivalent if the subject analytically heard-out a common root, third, or fifth (e.g., two chords might be judged as similar if they shared the same fifth). The author is not aware of any theoretical claims, however, that would support extraction of the third or fifth as more salient components than the root, and in an unpublished experiment conducted in our laboratory, it was indicated that when subjects were given the choice as to whether the root, third, or fifth sounded most similar to the triad, subjects who showed a preference tended to choose the root. The other subjects either did not show a preference, or tended to choose the highest note of the chord as sounding most similar to the triad, regardless of whether it was a root, third, or fifth.

The other manner in which the triads of the present thesis could be judged would be through synthetic listening for a common chord-chroma, and this would most-likely reveal the root-note or fundamental as the dominant percept. If the components of the major triad in root position are considered to be the fourth, fifth and sixth harmonics of a fundamental two octaves below the root, and if octave equivalence is accepted as a strong perceptual phenomenon, then perception of the fundamental, or root of the chord, would be expected to have a substantial influence on chord perception. Furthermore, because the three inversions of a triad can be written on the staff in such a way as to all imply the same fundamental two octaves below the root of each chord, and because the three components of the triads are simply the same notes written in different octaves, it might be expected that all three triads would be perceived as musically equivalent to one another. This equivalence could be the result of perception of the fundamental itself, or, due to octave equivalence, could be the result of root-note perception, since the root-notes of the three chordal positions are octave multiples of the same fundamental. These ideas are commensurate with those of Rameau (1722/1971) who felt that a common basse fundamentale was a necessary condition for inversion equivalence, and Terhardt (1974; 1978; 1984) who claimed that virtual pitch should be the pitch giving a chord its characteristic chroma (e.g., the virtual pitch of an A-major chord would be two octaves below the root, and give the chord its overall "A-quality," or chroma).

Support for the psychological reality of virtual-pitch perception has been found in our laboratory. One experiment tested the idea that root-note perception in triads was a result of virtual-pitch perception. If this was the case, then the harmonic relationship between the tones corresponding to a particular virtual pitch should have an effect on the strength of the virtual-pitch percept. Recall that if a major triad in root position is regarded as the fourth, fifth, and sixth harmonics of a fundamental (virtual pitch) two octaves below its root, that fundamental should contribute to the sense of chord chroma perceived by an individual. If the relationships between the triadic tones are altered so that they become less harmonic (i.e., the frequency components are not all integer multiples of the fundamental frequency) the percept of the fundamental should become weaker. These relationships become progressively less harmonic as one proceeds from major, to minor, to augmented, then diminished chords. The same professionals who were tested in our laboratory to see which tone they would choose as sounding most similar to a major triad, were required to choose the triadic tone which sounded most similar to major, minor, augmented, and diminished triads. The results showed that those subjects who chose the root-note in the first experiment also chose it in the second, and those who chose the highest note in the first experiment also chose it in the second. The results of the second experiment differed, however, in that subjects' choices of root-note, but not high-note, decreased with decreasing harmonicity of the triads. Choices of high-note actually increased with decreasing harmonicity of the triads. This pattern of results supported the hypothesis that subjects chose the root-note on the basis of perception of the fundamental, since fundamental perception would be expected to be less salient in the less-harmonic triads, with subjects possibly making choices of high-note as an alternative strategy to the root-note strategy.

In another unpublished experiment conducted in our laboratory, moderately-trained and inexperienced subjects were asked to vocalize the chroma that they perceived when listening to major, minor, augmented, and diminished triads. These subjects showed a tendency to vocalize either the root or the highest note of the triad, depending on triad type. Vocalizing the root was strongest for the major triads, while vocalizing the highest note was strongest for the other triads. This pattern was clearest for the moderately-trained subjects, probably because the inexperienced subjects often vocalized a chroma not contained in the triad.

If fundamental perception and/or octave equivalence is not as strong as predicted, then some other aspect of the chords may become the focus of perception. For example, the overall pitch-heights of the chords or their component tones could be the dominant perceptual feature. If analytic listening is the most prevalent strategy used by a subject, then the subject might judge two chords as sounding similar to the extent that the absolute frequencies of component tones within each chord are similar. It is possible, for example, that the subject could find the roots, thirds, or fifths of the chords more salient and proceed to judge two chords as sounding similar to one another if the tonal components are of a similar pitch-height. As already mentioned, however, in work done in our laboratory, subjects who showed a preference tended to choose the root-note as sounding most similar to the chord, and not the third or fifth. It is conceivable, therefore, that subjects in the present studies could proceed to judge the root-notes of the triads on the basis of their relative pitch-heights.

The other possible mode of analytic listening would be for the subject to consistently hear-out the low, middle, or high notes of chords, regardless of whether or not they function as roots, thirds, or fifths, and then proceed to judge these notes on the basis of their relative pitch-heights. This strategy seems a likely possibility in the present experiments, given the evidence in our laboratory for some subjects to choose the highest note of the triad as sounding most similar to the triad, regardless of whether it serves as a root, third, or fifth. Choices of the high-note seems a reasonable strategy, given that the melody-line in music is often carried by the highest notes in a harmony, or chord. Earlier experimental evidence provided by Farnsworth (1938) found that musically-trained subjects chose the highest note in a dyad (two tones played simultaneously) when asked to choose a tone which sounded most like the dyad. Farnsworth labeled such choices of the upper notes, melody-hunting.

Given the expectation that pitch-height judgements of the chords, if they occurred, would be guided by the highest note in each chord, the triads for each of the present experiments were ordered from low to high pitch-height based on the absolute pitch-height of the highest note of the chord. If two chords shared a highest note with the same pitch-height, then the decision as to which chord had the highest pitch-height was based on the middle and lowest notes of the chords. In this way, the chord possessing both a middle note and bass note with higher absolute frequencies than another chord would be said to have a higher pitch-height. Such a pre-determined ordering of the chords was necessary in order to have some basis of comparison when determining whether or not subjects were making triad similarity judgements using a pitch-height strategy.

Use of a pitch-height strategy might especially be the case for the less musically-experienced subjects, who, because of lack of formal exposure to the music system, would not be expected to have much experience with octave equivalence and fundamental detection. Furthermore, in the experiments conducted in our laboratory, the musically-inexperienced subjects showed no tendency to choose one note more than any other as sounding similar to the triad, while those with a moderate amount of training tended to choose the highest note as sounding most similar to the triad. One-half of the professional musicians also chose the highest note as sounding most like the triad, while the other half chose the root-note.

The second issue addressed in the present thesis was the ability of a major tonic triad in isolation to instantiate a sense of key. That major triads within musical contexts can provide a strong sense of key, and are perceived as entities toward which less stable entities resolve has been claimed in theory (Kohs, 1961; Ratner, 1962; Siegmeister, 1965), and demonstrated empirically (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982). Theoretically, however, claims have been made that these chords can function as stable units in the absence of any more elaborate musical context than the triad itself (Ratner, 1962). It is perhaps the case that these chords become musically meaningful only when presented in conjuction with other musically meaningful material. That is, in isolation, they may be perceived as mere sounds that can only be judged on a "less-musical" dimension such as pitch-height. One other way in which these triads could acquire musical meaning would be to have musically-experienced individuals judge them. It is perhaps the case that a musician attributes a musical meaning to all sounds, regardless of the nature of the sounds, whereas the appropriate frames of reference are nonexistent for musically-naive individuals.

If triads built on different tonics can represent the tonal centers of different keys, and if major triads built on different root-notes can be distinguished from one another on a basis other than their different pitch-heights, the question becomes one of the basis on which judgements concerning chordal relationships are made. Specifically, if the relationships between major triads are based upon key relatedness as exemplified by the Circle of Fifths, and if major triads are capable of instantiating key, then it is expected that judgements of isolated tonic triads will reveal an underlying structure in terms of the Circle of Fifths. That is, to the extent that the root-notes of two triads are also the tonics of different keys, subjects would be expected to judge these two triads as sounding similar to one another if their keys are considered highly related. If the tonics on which the triads are built represent distantly related keys, subjects are not expected to judge the triads as sounding similar to one another. Such a judgement strategy will be called a root-note strategy in the present thesis to distinguish it from a pitch-height strategy, in which triads would be expected to be judged on the basis of the pitch-height of the highest note of the chord (or, alternatively the middle and lowest notes when two chords share the highest note).

The final point investigated in the present experiments concerned the musical backgrounds of individuals who might be expected to perceive the highly-structured relationships between chords build on different root notes, and presented in different inversions. As stated earlier, musically-untrained individuals are at some level aware of the standards upon which Western tonal music is based. Although the musically experienced would be expected to have a more explicit knowledge of these practices, possessing the terminology to describe what one is hearing does not necessarily make one more aware of what is being heard. For this reason, individuals of varying levels of musical expertise were employed in the five experiments. The individuals tested were adults, and their range of experience across these experiments varied from no musical training through professional employment as musicians.

These thesis objectives were pursued using a two-alternative forced-choice paradigm in which subjects were presented with two pairs of triads, and asked to select in which pair the component chords sounded most similar to one another. No other musical context was provided. If it is the case that music-theoretic claims of harmonic equivalence among inversions, except for the second inversion in some cases, are correct, then all positions of triads built on the same root-note should be chosen as sounding equally similar to one another. At least this would be expected among the musically-experienced subjects. Furthermore, given that a sense of musical key has been acquired and can be evoked by an isolated triad, it was expected that subjects would choose triads as sounding similar to one another to the extent that their keys are considered highly related. Past research had indicated that internalized hierarchies of tones and chords are developed through exposure to the music system, so that inexperienced subjects would not be expected to use this basis of judgement, and would perhaps make their judgements on the basis of some other available cue, such as pitch-height.

Chapter II will discuss the statistical analyses used to discern whether any of the aforementioned structures were evident in the subjects' decisions, and whether utilization of these structures was dependent upon level of musical training. These analyses involved two somewhat uncommon techniques, multidimensional scaling and clustering, and therefore Chapter II will be devoted to them.

Chapters III, IV, V, VI, and VII will discuss Experiments 1, 2, 3, 4, and 5, respectively. Experimental manipulations in these studies included the number of keys examined, degree of relatedness between keys, manner of stimulus presentation (a constant standard chord vs a roving standard), direction traversed on the Circle of Fifths when a constant standard was employed, level of musical experience of the subjects, instructions regarding which aspects of the chordal stimuli were to be judged, and the structure of the chords presented (chords built through the combination of three pure tone components, and chords built in such a way as to obscure the qualities of pitch-height and inversion).

Chapter VIII will present a general discussion of the experiments.

CHAPTER II

STASTISTICAL ANALYSES

The analyses employed in the present thesis involved the use of a Group-Average-Method hierarchical clustering technique, and an individual differences scaling model, INDSCAL. To facilitate interpretation of the results from the five experiments, each technique will be discussed in the present chapter.

Multidimensional Scaling

Multidimensional scaling (MDS) developed from the belief that perceived similarity or dissimilarity between a pair of objects could be represented in a geometrical space. For example, different countries might be classifed on the basis of economic stability, with the perceived differences represented on coordinate axes. In this way, those countries considered more stable might be represented in the positive direction on the x-axis, while those considered less-stable might cluster toward the negative end. Another attribute, such as degree of conservatism/liberalism within the governments, could be represented in opposing directions on the y-axis. To the extent that two stimuli (or entities to be compared) are perceived as similar, the output of a MDS analysis should represent the two stimuli as very close to one another in a geometrical space. Likewise, if two stimuli are perceived as having dissimilar qualities, they should be depicted at a further distance from one another within the solution space.

The data for a MDS analysis are in the form of "proximities," or measures of the degree of similarity/dissimilarity between stimuli. These proximities can be obtained through a number of measures, including magnitude estimation, category sorting, or in the case of the present experiments, paired comparison judgements. Kruskal and Wish (1978) indicated that the attributes which are expected to be recovered in the stimuli are often not revealed to the subject making the similarity/dissimilarity judgement. This is done to avoid recovery of attributes, or dimensions, which are not especially salient to the individual. Guidance may be given, however, regarding the general direction in which judgements are to be focused (e.g., judge the musical styles rather than political persuasions of different countries). In the experiments of the present thesis, subjects were instructed to judge the similarity of musical triads, except in Experiment 5 where half of the subjects were instructed to judge how well one chord followed the other in a musical sense.

Davison (1983) defined MDS as "a set of multivariate statistical methods for estimating the parameters in and assessing the fit of various spatial distance models for proximity data" (p. 2). In MDS there are important assumptions regarding the relationship between similarity/dissimilarity and spatial distance. First, distance is usually taken to mean Euclidean distance, and the proximities are considered to be related to that distance. That is,

$$\delta_{ij} = d_{ij} = [\sum_{k=1}^{K}(x_{ik} - x_{jk})^2]^{1/2}$$

where δ_{ij} is the measurement of similarity/dissimilarity between stimuli i and j, d_{ij} is the estimated distance between stimuli i and j, and x_{ik} and x_{jk} are the coordinates of stimuli i and j, respectively, along dimension k. It is the goal of a MDS program to determine stimulus coordinates x_{ik} and x_{jk} from the dissimilarity measure, so that the experimental stimuli can be represented in an n-dimensional space.

The task of MDS algorithms is to approximate as nearly as possible the distances (d_{ij}) with the proximities (δ_{ij}). If the proximities were obtained from a dissimilarity measure, then there should be a positive relationship between the dissimilarity and distance representation. That is, the more dissimilar two stimuli are, the further apart their representation in the scaling solution. Alternatively, a similarity measure should correspond to a negative relationship with the represented distance.

The function which relates physical distance and psychological proximity is what defines different types of multidimensional scaling. Two of the major types of MDS are metric MDS and nonmetric MDS. The present thesis utilizes nonmetric scaling models, but these are more clearly understood when compared with metric scaling. Metric MDS can specify, in a formula, the exact relationship between the distances and proximities. For example, if the function is one which can be described by a straight line through the origin, the relationship could be characterized by something of the form: $d = b\delta$. Nonmetric MDS also specifies a relationship between distances and proximities, but it is less restrictive. For example, the relationship could describe a "rising pattern," without further specification of the relationships between values, as long as each successive data point is higher in value than the one which precedes it. Nonmetric scaling is characterized, therefore, by the rank order of the proximities, indicating either an increasing or decreasing function.

In the usual forms of MDS, the output consists of a group stimulus space in which the relationships between groups of objects are depicted for a group of subjects. Such a method of scaling is called two-way scaling, referring to the matrix of similarity/dissimilarity judgements between pairs of stimuli. There is another form of MDS, however, called three-way scaling, in which the input consists of individual two-way similarity/dissimilarity matrices, one for each subject tested. The output of three-way scaling consists not only of a group stimulus space, but also an individual subject space in which the differential saliences of dimensions recovered in the group solution are reflected in terms of individual subject weights. Subjects can then be shown to weight heavily on one particular dimension, several dimensions, or no dimensions at all. Furthermore, provision of a group space representation allows comparisons between the group stimulus dimensions. Such a method of scaling, also known as individual differences scaling, was employed in the present thesis. Selection of individual differences scaling for the present work was influenced by the diverse musical backgrounds of the subjects tested and the expectation that these backgrounds, along with the nature of the stimuli to be judged, would influence individual similarity/dissimilarity decisions. Although two-way scaling techniques are capable of processing multiple matrices, differences between matrices would have been accounted for as random error. Three-way scaling, on the other hand, handles these differences by determining specific relationships to the coordinate axes for individual subjects (Kruskal & Wish, 1978), differences which were felt to provide important information concerning judgement strategies.

The INDSCAL Model

The three-way model selected for use in the present thesis was INDSCAL, an individual differences model in the multidimensional scaling program ALSCAL (Young, Takane, & Lewyckyj, 1978). The input to such a program consists of a number of square data matrices[3], one for each subject tested[4], in which the proximities between pairs of objects comprise the entries within each matrix. Each matrix is then transformed into a symmetric dissimilarity matrix[5], through use of the Euclidean distance formula for each pair of objects between the rows of the matrices. The diagonal extending from the upper left-hand corner to the lower right-hand corner of the matrix contains entries of zero as a result of one of the distance axioms on which MDS is based, the axiom stating that identical objects should not be perceived as dissimilar to one another. The output of the analysis contains estimates of the group stimulus matrix and subject weight matrix, along with fit measures to show how well the resulting configuration corresponds with the data.

To proceed from the input to the output stages of the program requires a series of passes, or iterations, through the data. It is during these passes that attempts to bring the relationship between the distances (d_{ij}) and proximities (δ_{ij}) as close as possible are carried out, a process which is dependent upon the type of MDS model used. For the INDSCAL model, the algorithm can be described in a few major steps, the details of which are available through a number of sources (see for example, Carroll & Chang, 1970; Davison, 1983; Jones, 1983; Kruskal & Wish, 1978; The MDS (X) Series of

Multidimensional Scaling Programs, 1981).

The first step requires transforming the individual dissimilarity matrices into scalar product matrices. This is done by squaring each of the entries in a subject's data matrix, and then double-centering the entire matrix. Double-centering entails constraining the mean of the row entries and the mean of the column entries to equal zero. The matrices are then standardized to prevent any one subject's similarity/dissimilarity judgements from having an extreme effect on the resultant stimulus dimensions. Carroll and Chang (1970) recommended equating the variances for each subject's matrix by requiring each to have a sum of squares equal to one.

The next part of the procedure involves the derivation of a starting configuration from the values obtained in the first step. The initial configuration is derived only once, with all subsequent modifications to the configuration performed on the most recently derived version.

The third step marks the beginning of the iterative process during which steps are taken to estimate subject weights and stimulus coordinates. It is the function of the iterative process to "minimize the sum of squared discrepancies between the predicted and actual scalar products" (Davison, 1983, p. 145), calculated as F, where

$$F = \sum_{(i,j,s)} (\delta^*_{ijs} - \hat{\delta}^*_{ijs})^2.$$

Here, $\hat{\delta}^*_{ijs}$ represents the predicted scalar product, where

$$\hat{\delta}^*_{ijs} = \sum_k \hat{x}_{ik} \hat{x}_{jk} \hat{w}^2_{ks},$$

and $\hat{x}_{ik}$ and $\hat{x}_{jk}$ represent the estimates of the stimulus coordinates for stimuli i and j along dimension k, with $\hat{w}_{ks}$ representing the weight estimate for Subject s along Dimension k. In Davison's (1983) INDSCAL algorithm, iterations proceed until F is calculated to be less than some small pre-specified value. In the present thesis, iterations ceased when the improvement in S-STRESS (also a fit measure) fell below .001. Davison's final fit measure involves the report of the correlation between the predicted and actual scalar products. Several other fit measures, or "objective functions" (Kruskal & Wish, 1978), however, are available with INDSCAL analyses. These include S-STRESS and STRESS, calculated to show how well the resulting configuration fits the data, and RSQ values to indicate the proportion of variance in the data accounted for by the distance estimates.

The final steps of the algorithm involve one last estimation of the subject weights, and a standardization of the stimulus coordinates.

Fit Measures. Three fit measures were included in the output of the present INDSCAL analyses: Kruskal's STRESS Formula 1, Young's S-STRESS Formula 1, and the proportion of data variance accounted for by the distance estimates (reported as RSQ). Both the STRESS and S-STRESS measures are "badness-of-fit" measures, such that lower values indicate a better fit to the data. The RSQ measure is a "goodness-of-fit" measure, with higher values (up to 1.0) indicating more variance accounted for by the model.

Kruskal's STRESS Formula 1 (see Davison, 1983; Kruskal & Wish, 1978) was used to indicate how well the data for individual subjects were fit by the resulting configurations. The STRESS measure assumes some function between the proximities (δ_{ij}) and distances (d_{ij}), and then calculates deviations between the two measures. Because distinctions are not made between deviations in a positive or negative direction, each of the values is squared. This procedure is followed for each proximity, with the resulting values summed

$$\Sigma_{(i,j)} [f(\hat{\delta}_{ij}) - \hat{d}_{ij}]^2.$$

The proximity estimates $\hat{\delta}_{ij}$, technically known as disparities, are calculated to be as close as possible to the distance estimates $\hat{d}_{ij}$, while preserving the monotonic relationship between them. The obtained value is then divided by the sum of squared distance estimates, $\Sigma_{(i,j)}\hat{d}^2_{ij}$, what Kruskal and Wish (1978) call their "scale factor," and what Davison (1983) calls the "normalizing constant." The last step involves taking the square root of the entire formula,

$$[\Sigma_{(i,j)}(\hat{\delta}_{ij} - \hat{d}_{ij})^2 / \Sigma_{(i,j)}\hat{d}^2_{ij}]^{1/2},$$

resulting in STRESS Formula 1.

Young's S-STRESS Formula 1 was the S-STRESS variation used to indicate how well the data for the subjects as a group fit the configuration. The S-STRESS formula differs from the STRESS formula in that the distances and disparities are squared

$$SS_1 = [\Sigma_{(i,j)}(\hat{\delta}^2_{ij} - \hat{d}^2_{ij})^2 / \Sigma_{(i,j)}(\hat{d}^2_{ij})^2]^{1/2}.$$

The RSQ measure represents the correlation between the actual and estimated scalar products. Both individual subject RSQ values and mean RSQ values for all subjects tested were provided in the INDSCAL analyses of the prsent thesis. A more detailed description of these correlations is available in Davison (1983, p. 130-131).

Dimensionality. Dimensionality refers to the number of coordinates needed to specify the location of a stimulus point. Because a MDS program will usually be used to provide solutions in several dimensions, a decision must be made regarding the appropriate dimensionality for a scaling solution, a task involving a number of somewhat intuitive decisions.

One way to approach the problem is to examine the STRESS values derived for the different dimensionalities. For the individual differences scaling used in the present experiments, it is the average STRESS values over subjects that one wants to examine. This can be done by plotting a STRESS-by-Dimensions graph and looking for a clear elbow in the graph, an elbow that should fall directly over the preferred dimensionality. Interpretation of where the elbow occurs is not always apparent, however, and the degree of sharpness can vary between the solutions. To complicate matters, the group space of an individual differences scaling program will more than likely contain a large number of dimensions "since it may well include purely idiosyncratic dimensions" (The MDS (X) Series of Multidimensional Scaling Programs, 1981, p. 0.13).

Kruskal and Wish (1970) cautioned against accepting dimensions with a STRESS > .10 in the usual forms of MDS. Davison (1983), however, when discussing nonmetric group solutions, claimed that a solution with STRESS > .10 could be accepted if measurement or sampling error were problems within the design. Although the author of the present thesis could find no claims in the literature that average STRESS values for an individual differences scaling analysis tend to be higher due to the low fits exhibited by some subjects, such a statement does have intuitive appeal and should be kept in mind when interpreting the present data. Furthermore, given the claim made in the MDS (X) Series of Multidimensional Scaling Programs (1981) that a higher number of dimensions may be necessary to explain an individual differences scaling analysis, and because STRESS values tend to decrease as the number of dimensions increase, it may be that higher average STRESS values for individual differences scaling are the rule rather than the exception.

Kruskal and Wish (1970) discussed variables which could affect STRESS, one of which is the number of stimuli that were used in the scaling procedure. If the number of stimuli is very large relative to the number of dimensions, then the effect on dimensionality is small. To minimize this effect they recommended that the number of stimuli presented should be four times the number of dimensions expected. Davison's (1983) estimate of three or more stimuli for each expected dimension is commensurate with this value.

Rotation. Ordinary MDS solutions can be rotated, objectively or subjectively, so that the dimensions lend themselves to meaningful interpretation. Rotation is permissible in such solutions because the output of these analyses reflects the distances between the stimuli, distances which do not change as a result of rotation. With individual differences scaling, however, the solution is intentionally derived with respect to the coordinate axes. Individual subject weightings "expand" and "contract" the location of stimuli on the coordinate axes, rendering rotation of the solution meaningless. It is expected, therefore, that interpretation of an individual differences output should be readily apparent, and Carroll and Chang (1970) cited a number of supportive instances where meaningful interpretation of the dimensions was possible without rotation.

The differential weighting of the group space can be represented in terms of what Carroll and Chang (1970) call a "modified" Euclidean distance

$$\hat{d}_{ijs} = [\sum_{K} \hat{w}_{ks}(\hat{x}_{ik} - \hat{x}_{jk})^2]^{1/2},$$

where estimated subject weights, w_{ks}, are incorporated into the Euclidean distance formula.

Interpretation. The output of an INDSCAL analysis includes a group solution space and a subject space, each of which requires interpretation.

Regarding the group solution, it is usual to obtain MDS solutions in several dimensionalities, one of which must be selected as best representing the data. Davison (1983) suggested choosing the lowest dimensionality for which all the important stimulus groupings are represented, a decision dependent on subjective impressions of the adequacy of the stimulus configuration. One may look for expected orderings in the data based on the nature of the stimuli, or may discover the presence of an unexpected dimension, leading to speculation of alternative strategies that subjects could have used to judge the stimuli.

Kruskal and Wish (1978) described the existence of "neighborhood interpretations." These are meaningful orderings within clusters of stimuli in the group solution that do not necessarily correspond to the global interpretation associated with one of the dimensions. It is possible that displaying such a solution in a higher dimensionality would provide the necessary number of dimensions to capture this additional structure. Kruskal and Wish (1978) suggested the use of exploratory cluster analysis on the proximity data to determine what types of structure are likely to be found in the neighborhood groupings, or within the neighborhoods themselves. They caution against placing too much emphasis on order interpretations within neighborhoods, however, especially when the solution is of a low dimensionality, since acceptance of a higher dimensional solution could help in interpreting the structure. Also, they state that "MDS does a much better job in representing larger distances (the global structure) than in representing small distances (the local structure)" (p. 46).

The subject space, or "weight space" also must be interpreted. These weights are indicative of the relative salience of the dimensions for individual subjects. When interpreting the scaling solution, the weights can be helpful in determining commonalities in subject backgrounds among subjects who express similar patterns of weightings on the dimensions. Jones (1983) and The MDS (X) Series of MDS Programs (1981) described the subject weights in terms of vectors extending from the x-y coordinate origin when those coordinates represent dimensions in the solution space. The closer an individual subject weighting is to the origin, the less of that subject's variance is accounted for by the model. Further, if a subject's weight estimate falls on a line 45^0 between the axes, then the judgements are described by an equal weighting on the two represented dimensions. Falling off the 45^0 diagonal toward either axis indicates a stronger weighting on that dimension relative to the other in a two dimensional plot.

Cluster Analysis

Cluster analysis, as defined by Aldenderfer and Blashfield (1984, p. 7) is a "multivariate statistical procedure that starts with a data set containing information about a sample of entities and attempts to reorganize these entities into relatively homogeneous groups." The need to classify objects into relatively discrete categories is intuitively obvious, but unfortunately somewhat difficult to do in a rigorous manner. For example, there is no generally agreed upon definition of what constitutes a homogeneous class (Cormack, 1971), and the use of various clustering methods often results in the emergence of different clusterings of objects (Aldenderfer & Blashfield, 1984), with the amount of recovery often dependent upon the type of data clustered (Milligan, 1980).

Given the inherent difficulties of clustering, the method of analysis chosen for the present thesis, the Group Average Method, was one which has been shown to minimize some of these problems. For example, when Milligan (1980) submitted data sets with different types of error perturbations to 11 hierarchical agglomerative methods and 4 nonhierarchical centroid sorting procedures, the Group Average Method was ranked among the top 3 methods, in terms of cluster recovery, for 8 of 10 error conditions. In particular, the Group Average Method was found to be resistant to the presence of outliers (see also Aldenderfer & Blashfield, 1984), a condition which was expected to pose some problems in the experiments of the present thesis. The other perturbations in Milligan's, 1980, study included an error-free condition, distance perturbations, inclusion of random noise dimensions, use of non-Euclidean similarity measures, and standardization of the data before calculating Euclidean distances.

The Group Average Method is one of a number of <u>hierarchical agglomerative</u> clustering methods. <u>Hierarchical</u> refers to the pattern of linkages between objects, such that each object is first represented as an independent entity (cluster), and then successively joined to other objects until all are subsumed by one large cluster. Agglomerative is the term referring to how these linkages are achieved. Specifically, objects perceived as most similar to one another are joined before objects considered to have a greater degree of dissimilarity between them. The calculation of the separation between the objects is what characterizes different clustering techniques.

The Group Average Algorithm

The input to a cluster analysis program consists of a N x P square data matrix, one for each subject, where N refers to the observations or cases, and P refers to the variables. In the present thesis, these data entries were in the form of each subject's raw choice scores. The data matrix is then transformed into a dissimilarity matrix through use of the Euclidean distance formula, resulting in a half-matrix with a zero diagonal.

Calculation of the separation between objects (or clusters of objects) can then proceed. The Group Average Method does this by weighting the dissimilarity between each cluster by the number of objects in each cluster,

$$d(ki) = m(p)d(pi) + m(q)d(qi) / m(p) + m(q),$$

where d(ki) is the separation value calculated for the formation of a new cluster k, consisting of i objects, formed as a result of the linkage of clusters p and q, where m(p) and m(q) represent the number of objects in clusters p and q, respectively, and d(pi) and d(qi) represent the existing separation values, or distances, for clusters p and q, respectively, over i numbered objects. In the first pass through the data, each cluster will consist of only one object. At this step each object will be compared to every other object, with the most similar objects (i.e., those objects with the least average distance between them, as calculated with the above formula) being joined as the first linkage in the clustering result. As objects join to form a new cluster, the new cluster becomes an "object," such that subsequent passes will once again involve pairwise comparisons between all pairs of objects, some of which will already be in the form of clusters. The procedure continues joining objects with the least average distance between them, until all have been joined to one another.

The output to such a hierarchical clustering program can be clearly represented in the form of a dendrogram, a tree-like structure depicting the level of dissimilarity at which linkages occurred between the objects. Along the x-axis of a dendrogram is shown the objects that were clustered, while along the y-axis is shown the separation value (labeled dissimilarity) at which each of the linkages occurred. Sample dendrograms can be seen in Figures 13, 14, 15, 22, 35, and 36, which were included as part of Experiments 1, 2, and 5 in the present thesis. Reading a dendrogram involves following the connection (linkage) between any two objects, or groups of objects. Objects which are directly joined by a particular linkage are taken to reflect a high degree of perceived similarity between those objects, relative to the other objects in the stimulus set. Another important indicator of perceived similarity is the height on the y-axis at which two objects are joined. The higher the level at which the linkage occurs, the more dissimilar the perceived similarity between the objects.

Interpretation of the resulting dendrogram involves decisions as to what will be accepted as a criterion for the separation of clusters, that is, the level of the dendrogram at which the existence of a complete cluster is accepted. Such a decision is potentially controversial when it is considered that these criteria are often set with the knowledge of experimental hypotheses. Everitt (1980, p. 44) offered a description of clusters as "continuous regions of...space containing a relatively high density of points, separated from other such regions by regions containing a relatively low density of points." Vague as this definition appears, it characterizes the views of a number of researchers (Aldenderfer & Blashfield, 1984; Milligan, 1980; Sneath & Sokal, 1973). Cormack (1971, p. 329) stressed the interpretative problem with regard to experimental expectations when he stated, "In the social sciences the search has been for tight clusters or cliques in which each entity resembles every other, and in which all are satisfactorily described by one--the profile of the set." In the present thesis, examination of a resulting dendrogram proceeded through a combination of searching for clusters on the basis of proposed strategies that subjects might use to judge musical triad similarity, and also of searching for tight, compact clusterings when these expectations were not fulfilled, in the hope of discovering alternative strategies that subjects may have been using.

Multidimensional Scaling and Cluster Analysis as Complementary Procedures

In the present thesis, both cluster anlaysis and MDS were used on the same data, a procedure advocated by others (Kruskal, 1977; Kruskal & Wish, 1978; Shepard, 1980). The cluster analysis served as a preliminary, exploratory measure to the MDS, conducted in efforts to obtain direction as to what types of strategies subjects might be using to judge the musical stimuli. These stimulus orderings, supposedly reflecting these strategies, could then be more readily interpreted in the scaling solutions.

Davison (1983) listed a number of shared characteristics between clustering and scaling. These included: analyses conducted on proximity data, use of distance models, and ability to depict results in terms of a coordinate system. The differences between the methods, however, are what contribute to their complementary nature. Kruskal (1977) mentioned the statistical folklore that MDS reflects the large differences between stimuli, whereas clustering displays small differences. That is, stimuli appearing within close spatial proximity in a scaling solution are often not significant orderings because slight changes in the data could result in large fluctuations of those local orderings, but not in the global solution. With a clustering solution, however, local linkages between objects are usually meaningful connections reflecting significant relationships between those stimuli, but the larger connections often do not lend themselves to interpretation. This can probably be better understood when considering MDS as depicting the continuous nature of stimuli (in terms of a continuous multidimensional space), with clustering reflecting the discrete characteristics of the stimuli (in terms of discrete linkages, as in a dendrogram).

Davison (1983) listed other differences between the two methods. For example, the goal of MDS is to express the relationship between the proximities and distances in terms of a monotonic or linear function, a relationship which often cannot be expressed in cluster analysis. Also, the distances which are taken to be spatial distances in MDS are not considered spatial entities in clustering.

In the present thesis, subjects were presented with a paired-comparison task. Two pairs of musical chords were played, and subjects were asked to choose the pair, on a trial, which they felt sounded most similar to one another. Subjects were cautioned that the first chords of each pair on a trial were the same, and that these chords were meant to serve as the standards to which they should make their similarity judgements. That is, they were asked to judge the similarity of the second chord to the first, and then choose the pair in which the component chords sounded most similar to one another. For any set of stimuli within Experiments 1, 2, and 5, there was complete counterbalancing so that each of the stimulus chords served as the standard an equal number of times. Because of this directionality in the similarity judgements, the cluster analyses were performed by comparing patterns of choice scores obtained for each of the standard chords in response to each of the choice chords. In this way, it was actually the standard chords for which the clusters (as represented in dendrograms), and the spatial distances (as represented in the scaling solutions), were calculated. Therefore, if two (or more) standard stimuli had a similar pattern of choice scores across the comparison chords, the standard chords would be assumed to have been perceived in a similar manner, and this would be reflected by a close linkage of these standard chords in the dendrogram, or alternatively, by close spatial proximity in the scaling solution.

Experiments 3 and 4 differed from Experiments 1, 2, and 5 in that the standard chord not only remained the same within the two pairs presented on a particular trial, but it also served as the standard across all trials within the experiment. In these two experiments, an alternative preliminary analysis, involving the calculation of correlations between a subject's actual profile of choice scores and each of two predicted profiles of choice scores, was used. Each of these predicted profiles represented an expected outcome, if a particular strategy had been used to judge the musical stimuli. To the extent that a correlation with one of these profiles was high relative to the other, it was assumed that a subject was making use of that strategy to some degree. This change in method of preliminary analysis was invoked because it was felt that the correlation analysis would provide a more direct answer as to whether one of the two predicted strategies was used by a subject. If cluster analysis had been employed, the resulting dendrogram would have to be interpreted for results indicative of one of the predicted strategies, or some other strategy usage. Earlier experiments had indicated, however, that the strategies used were primarily one of two types, with few of the subjects giving evidence of some other strategy usage. The MDS analyses for Experiments 3 and 4 differed from those of Experiments 1, 2, and 5 in that they were used to scale the choices of each stimulus chord in response to the constant standard chord. This was done by constructing an N x P matrix, in which N represented the comparison chords presented with the standard in the first pair of chords, and P represented the comparison chords presented with the standard in the second pair of chords. To the extent that a subject's pattern of choices for comparison chords presented in second pairs was similar for comparison chords presented in first pairs, those chords presented in first pairs would be assumed to have been perceived in a similar manner. In this way, it was actually the first-pair chords which were scaled in the scaling analysis.

There were two differences between the clustering and scaling with regard to interpretation of the experiments in which they were both used.

These concerned data entry and the subsequent formation of the dissimilarity matrices. For the cluster analysis, data entry consisted of the total number of times each of the comparison chords was chosen as sounding similar to each standard chord, and the dissimilarity matrices were formed through use of the Euclidean distance formula. For the MDS analyses, data entry took the form of binary data, where a 0 was entered if the comparison chord of the first pair was chosen, and a 1 if the comparison chord of the second pair was chosen. Given the possible values of 0 and 1, the Euclidean distance formula was not used to derive a dissimilarity matrix for these data. Instead a measure of binary association, Simple Matching, was used. The Simple Matching formula takes the form $(a + d)/n$, where a represents the number of times a choice of both the first comparison chord and the second comparison chord was made, d represents the number of times a choice of neither the first comparison chord nor the second comparison chord was made, and n represents the total number of binary cases measured (i.e., the sum total of times both the first comparison chord and second comparison chord were chosen + the number of times neither the first comparison chord nor the second comparison chord were chosen + the number of times the first comparison chord but not the second comparison chord was chosen + the number of times the second comparison chord but not the first comparison chord was chosen). The use of binary values provided a greater number of variables for the scaling analyses, an important consideration, as discussed previously under the subheading of multidimensional scaling.

CHAPTER III

EXPERIMENT 1

Experiment 1 was conducted in order to determine the perceived similarities between major tonic triads in different positions (root, first inversion, and second inversion), and between major tonic triads built on the tonics of two maximally-related keys, A major and E major. This was accomplished using a two-alternative forced choice paradigm in which subjects were presented with two pairs of chords, and asked to select which pair sounded most similar to one another. The ambiguous instruction, to judge "similarity" of the chords, was purposely given to subjects so as not to bias their judgements in the direction of pitch-height, root-note, inversion, or any other possible strategy. In this way, it was hoped that subjects would judge the chords on the basis of whatever chordal dimension they found most salient, although several strategies might be available to them.

In order to ascertain whether or not subjects' judgements were reflective of the theoretical differential stabilities between chord positions, such as the second inversion functioning as a less stable unit than the root and first inversions, subjects were told to judge all pairs as if the first chord of the pair was a standard and to judge the second chord in relation to this standard. The instruction to judge the first chord as the standard would also allow interpretation of subjects' choices in terms of whether or not chords built on the same root-note were more often chosen as sounding similar than those built on different root-notes.

The choice of two maximally-related keys, which are adjacent on the Circle of Fifths, and therefore, share a number of scale tones and chords, was done in order to investigate the possibility that position similarity would transfer across keys. Krumhansl, Bharucha, and Kessler (1982) had found that chords with identical tonal functions were rated as highly similar even if they were of different chord types (e.g., major and minor), leading to speculation in the present experiment that chords in the same position could possibly be perceived as similar. This would especially be expected under circumstances where the keys from which they were drawn were expected to be perceived as highly similar.

Given the claims that major triads function as strong tonal units, the triads in this experiment were presented in the absence of any other musical context. If it is the case that the tonality of the triads is a dimension that is more salient than position, then subjects would be expected to choose those chords built on the same root-note as sounding very similar to one another. To facilitate the perception of these chords as tonal entities, steps were taken to minimize interpretation of these chords on the basis of pitch-height. Although pitch-height effects could never be entirely eliminated, due to the obvious necessity that tones comprising chords of different inversions occupy different locations on the musical staff, the three positions of these tonic chords were written as close as possible in terms of pitch. Furthermore, the second-inversion E-major chord (2E) and first-inversion A-major chord (1A) were written on the staff to be the most similar of all chordal stimuli in terms of pitch-height. This was done as a check on whether or not subjects were judging the similarity of the chords on the basis of pitch-height, inversion, or root-note, since if subjects chose these chords as sounding very similar to one another, it could only be on the basis of pitch-height, since they differed in inversion and root-note.

Another attempt to reduce pitch-height judgements in this experiment was the inclusion of two chords of the type designed by Shepard (1964). These chords were not only used as a control for pitch-height, but also inversion, so that subjects might be coerced into making their similarity judgements on the basis of overall chord chroma, or the pitch corresponding to the root or virtual pitch of the chord. Furthermore, the Shepard chords, as they will be referred to for easy reference in the present thesis, for A and E major were both centered at 660 Hz, which was an intermediate frequency for all chords used in the experiment. In this way, no one chord would deviate significantly from the other chordal stimuli in terms of pitch-height. If the Shepard chords strongly conveyed chord chroma, it would be expected that subjects would judge the A- and E-major Shepard chords as sounding very similar to their A- and E-major chord counterparts, which were built in the conventional manner of three tonal components sounded simultaneously.

In the present experiment, it was possible that subjects could make their similarity judgements on the basis of the fundamental root. Given the determination that the fundamental root for a major triad occurs two octaves below the root of the triad (Hall, 1980; Ratner, 1962), the location of each chord built on the same root-note was written on the staff so that all chordal positions shared the same fundamental root. Each Shepard chord had a unique fundamental root.

The subjects tested were of three levels of musical training: inexperienced, moderately experienced, and professional musicians. Subjects with a wide range of training backgrounds were used in order to test the proposal that presentation of major triads in the absence of more elaborate cues to musical key, might be sufficient for the more highly-trained subjects to judge the triads as musical entities, as evidenced by judgements based on root-note. The less-skilled individuals, however, might need more context in order to shift from a "psychoacoustical mode," in which pitch-height judgements prevailed, to a musical one. Roberts and Shaw (1984) had found that sensible chordal judgements in the absence of a musical context, could only be obtained from their most highly-trained group. Krumhansl and her colleagues had also found sensible orderings, but had done so with subjects possessing less experience than those in the Roberts and Shaw study. Most of the Krumhansl studies, however, had provided a musical context in the form of scales, chords, or cadences as explicit cues to musical key. Due to the music-theoretic claims that the major triad in isolation serves as a strong instantiator of key (Ratner, 1962) and the empirical evidence supporting this assertion (Krumhansl, Bharucha, & Kessler; Roberts & Shaw, 1984), it would seem that by testing subjects with more advanced musical training, the proposed hierarchies could be automatically invoked without the prompting provided by a richer musical context. This proposal was tested by including professional musicians, along with less-skilled individuals, in the present study.

Method

Subjects. Forty-two individuals served as voluntary subjects. Of these 42 subjects, 5 were recruited because of their extensive musical training. These included 2 professors and 1 graduate student in the Department of Music at McMaster University, an undergraduate psychology student, and an individual who had recently received his undergraduate degree in biology. The remaining 37 subjects included 35 students from an undergraduate introductory psychology course, an undergraduate thesis student in the McMaster University Music Laboratory, and the experimenter herself. The subjects were grouped according to 3 experience levels: professional musicians, moderately-trained musicians, and musically-untrained individuals. The formal training of the 5 highly-trained subjects, labeled professionals, ranged from 10.0 to 16.5 years on their self-designated primary instruments (mean = 13.1 years). For one of these subjects, her primary instrument was voice, having received 10 years of voice lessons. All subjects reported theory training (which ranged from grade 3 harmony to having obtained a Ph.D. in music theory), and 4 of the subjects played more than one instrument. All of the subjects reported present and/or prior participation in other musical activities such as band and choir, and many of these functions were at the professional level. The experimenter attempted to determine current musical involvement in the form of playing one's primary instrument, and musical activity in terms of number of hours per day spent listening to music (music played on the radio, records, and tapes). The 5 professionals, however, appeared to have great difficulty in estimating these figures. It was perhaps because they so often spontaneously played their instruments throughout the day, or listened to music in general, that it was a cumbersome task. The less-experienced subjects seemed to quite easily arrive at the amount of time spent engaged in these activities. When asked about musical involvement of family members (number who played instruments and frequency with which they were played), all 5 subjects reported relatives who at some time played a musical instrument. Two of the professional subjects reported having absolute pitch, but stressed that the ability emerged only when tested with particular instruments. Of these 5 highly-trained subjects, 3 were male and 2, female.

The 20 subjects designated moderately trained were recruited as participants only if they met this experiment's minimum criterion of at least 3 years of music lessons on at least 1 musical instrument. Two further stipulations demanded that these music lessons were received under the auspices of private instruction, and that the subject currently played a musical instrument at least occasionally. The training of these 20 subjects ranged from 3.0 to 14.0 years on their self-designated primary instruments (mean = 7.3 years). Nineteen of the 20 subjects reported theory training (mean level attained = 2.4 years), and 16 of the subjects played more than one instrument. Eighteen of the subjects also reported prior participation in other musical activities such as band and choir. Current musical involvement in the form of playing one's primary instrument was reported at an average of 5.3 hours per week, while mean listening activity per day was reported at 3.0 hours. Fifteen of the 20 moderately experienced subjects reported family members who at some time played a musical instrument. No moderately-experienced subject reported having absolute pitch.

Of these 20 subjects, 4 were male and 16, female.

The remaining 17 subjects were classified as musically inexperienced. Fifteen of these subjects reported minimal instrumental training, usually consisting of lessons taught as part of a music class (mean = 1.4 years). Ten subjects also reported singing in a choir, but their experience was limited. These subjects reported an average of 2.9 hours per day of listening to music. Twelve of the 17 inexperienced subjects reported familial involvement with music. Within this group 8 were male and 9, female.

All subjects reported normal hearing.

Apparatus. Musical stimuli were generated by a DMX 1000 Signal Processing Computer controlled by an LSI 11/23 general purpose digital computer. These stimuli were amplified through an Avance DC Stereo Power Amplifier (Model Z501) and then played to the subjects through Realistic Pro IIA Headphones. Subjects received instructions to respond and take breaks through a C. Itoh video terminal (model CIT-101e). Responses were recorded by depressions on one of two buttons on a three-button response box. Subjects listened to all stimuli while seated in a sound-attenuated chamber.

Stimuli. Each trial consisted of the presentation of two pairs of chords. All tones comprising the chords were sine waves and were of A-just temperament.

Chords used in this experiment were of two types: (a) the root, first inversion, and second inversion of the chords built on the tonic (I) tone of the A-major and E-major scales; (b) chords built on the tonic (I) tones of the A-major and E-major scales but constructed in such a way as to obscure the perception of inversion (see Krumhansl, Bharucha, & Kessler, 1982, and explanation to follow). The A-major chords built on the tonic (I) tone of the scale consisted of an A-major root chord (A: 440 Hz, C#: 550 Hz, E: 660 Hz), first inversion (C#: 550 Hz, E: 660 Hz, A: 880 Hz), and second inversion (E: 330 Hz, A: 440 Hz, C#: 550 Hz). Analogous positions were constructed for the E-major chords built on the tonic (I) tone of that scale resulting in an E-major root chord (E: 660 Hz, G#: 825 Hz, B: 990 Hz), first inversion (G#: 825 Hz, B: 990 Hz, E: 1320 Hz), and second inversion (B: 495 Hz, E: 660 Hz, G#: 825 Hz). The second inversion E (2E) and first inversion A (1A) chords were constructed to be as close in pitch as possible. In this way, it was hoped that these two chords would serve as a flag for subjects selecting chords on the basis of pitch-height and not root-note or inversion. That is, if a subject consistently chose these two chords as being very similar to each other, one could be fairly confident that they were rated on the basis of pitch-height, and not on some other stimulus attribute, such as root-note or inversion, because the two chords were of different inversions and root-notes, but were very similar in pitch-height. (See Figure 10A for a diagram of the stimulus chords in the order of increasing pitch-height, and Figure 10B for the musical notation of these stimuli grouped by common root-note.)

Construction of the chords which obscured inversion but retained their respective qualities of key (i.e., the I chord from each key presented), came from a method described by Shepard (1964), and more recently by Krumhansl, Bharucha, and Kessler (1982). By building these chords in such a way so as to prevent presentation of an identifiable highest or lowest pitch, the

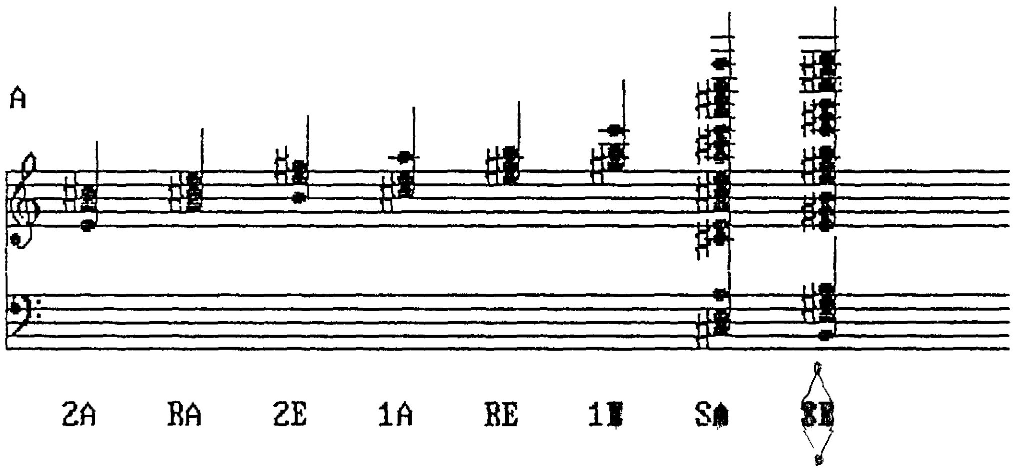
Figure 10. Musical notation of stimuli used in Experiment 1.

A: Triads presented in order of increasing pitch-height.

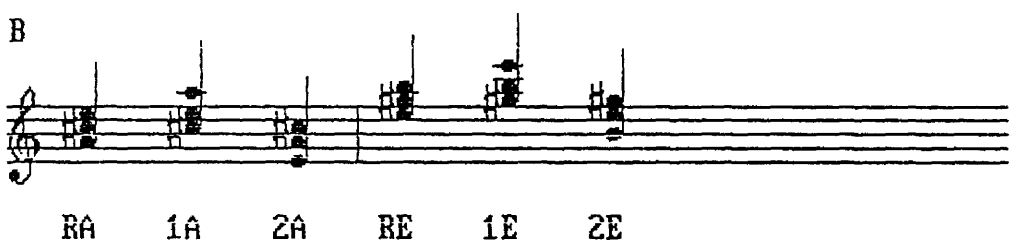
B: Triads grouped by common root-note.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E= First Inversion E; 2E = Second Inversion E; SA = Shepard A; SE = Shepard E)

A



B



assumption is made that one should be unable to perceive inversion; and therefore, be unable to judge the Shepard chords on the basis of pitch-height. These chords were built, using the three tone components comprising the triads, over a 5 octave range from 123.75 Hz to 3960.00 Hz. The loudness envelope over this frequency range gradually increased from threshold to 60 phons for 1 1/2 octaves where it leveled out for 2 octaves and then decreased to threshold again over another 1 1/2 octaves. In this way, no identifiable highest or lowest pitch could be identified. Figure 11 contains the loudness envelopes of the A- and E-major Shepard chords. The part of the function which is increasing was a cumulative normal distribution from -2.125 to 2.125 , and the decreasing part of the function was symmetric in form to the increasing pattern. The intensity (in dB) at which each frequency was sounded was calculated through use of the Fletcher-Munson diagram (Hall, 1980, p. 117). Amplitudes were then calculated for each frequency from an equation given by Roederer (1975, p. 80, cited in Krumhansl, Bharucha, & Kessler, 1982):

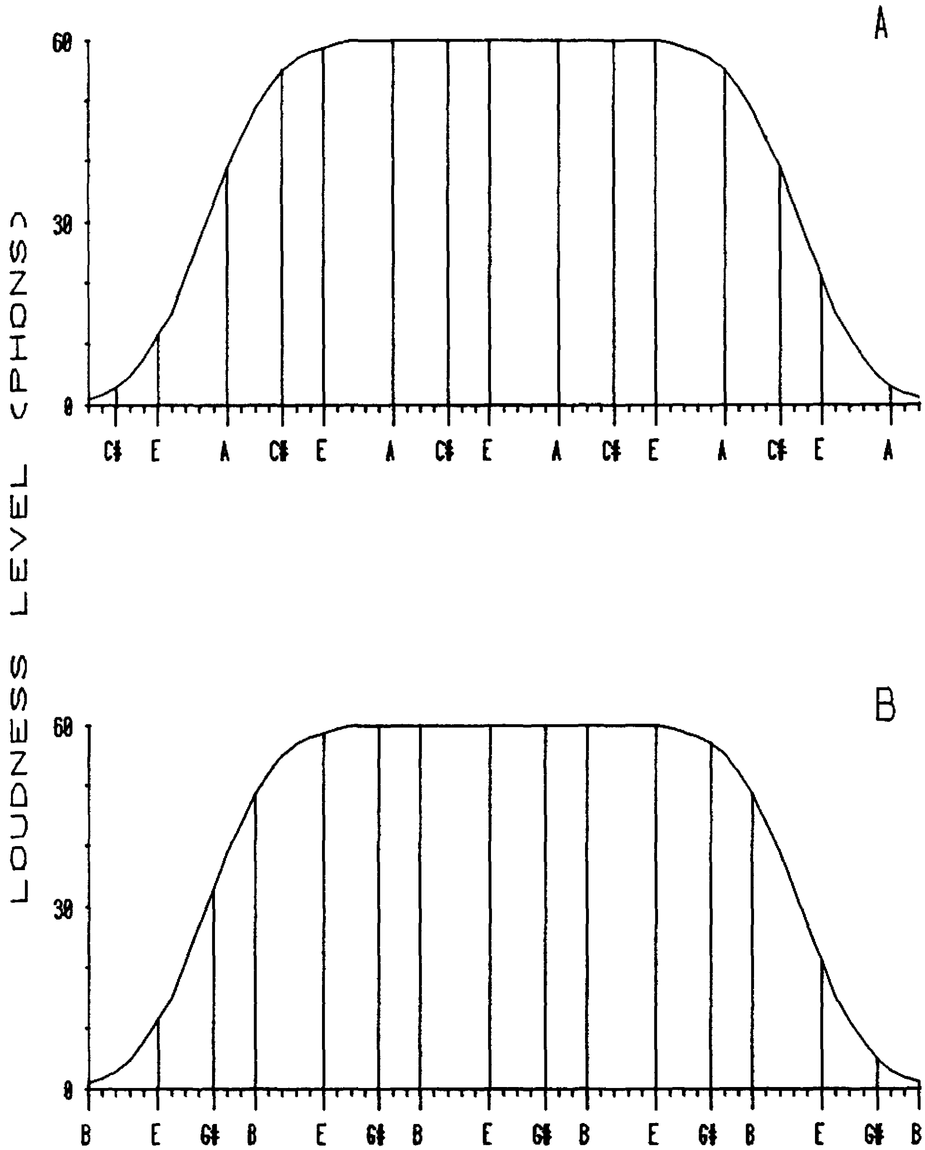
$$A = 10^{(I/20 + \log A_0)},$$

where A represents the amplitude of the frequency in question, I is the sound intensity level (in dB), and A_0 is the amplitude of a 1000 Hz tone at the loudness threshold.

The A-major chord was constructed from a digital representation of 15 sinusoidal components (3 triad tones of the A-major chord in each of 5 octaves), whereas the E-major chord contained 16 sinusoidal components (3 triad tones of the E-major chord in each of 5 octaves, plus an extra tone taken

Figure 11. A: Loudness envelope as a function of log frequency for A-major chord (referred to as Shepard A, or SA, in text).

B: Loudness envelope as a function of log frequency for E-major chord (referred to as Shepard E, or SE, in text).


A
B
LOUDNESS LEVEL (PHONS)
60
30
0
C# E A C# E A C# E A C# E A C# E A
B E G# B E G# B E G# B E G# B E G# B

from a sixth octave). The reason for the discrepancy in frequency sampling between the two chords was a desire to equate the two chords for pitch-height, and thus they were constructed in such a way as to center the frequency range of each chord at E = 660 Hz, and to represent each chord with an identical envelope.

The sampling rate for all 8 stimulus chords was 20,000 Hz. To prevent aliasing, a low-pass filter cutoff was set at 10,000 Hz. Rise and fall times were set at 50 msec. Measurement with an artificial ear and SPL meter indicated the A-major and E-major root, first inversion, and second inversion chord presentations to be at 75$\pm$1 dB SPL. The Shepard chords were judged by two observers to be at an equivalent loudness level with the root triads when presented at 70$\pm$1 dB SPL. The need to present the Shepard chords at a lower level was likely due to the larger number of frequency components separated by at least a critical bandwidth present in these chords, as compared to each of the other 6 stimulus triads.

The fundamental root was 110.0 Hz for the A-major chords, 165.0 Hz for the E-major chords, 27.5 Hz for the Shepard-A chord, and 41.2 Hz for the Shepard-E chord.

A trial consisted of 0.5-sec presentation of a chord, followed by a 0.5-sec pause, and then another presentation of a 0.5-sec chord. This represented the first pair of chords. The first pair was separated from the second pair by a 1.0-sec pause, and the same duration parameters were applied to the second pair (0.5-sec chord followed by 0.5-sec pause, followed by 0.5-sec chord). At this point a configuration representing the response box was presented on the monitor (see Figure 12). This representation contained labels indicating that the button on the left side of the response box was for the first pair of chords, that the button on the right was for the second pair of chords, and that the button in the middle was not applicable to any responses to be made in the experiment. The printed message, "RESPOND," appeared over the figure of the middle button after the second presentation of chords indicating that the subject should make his response at that time. There was no limit to the time allotted for a subject's response. As soon as a response was made in which the subject had depressed either the left or right button with the proper force, the respond message disappeared and a new trial immediately ensued.

There were three trial blocks in between which subjects were given a 5-min break from the experiment. These breaks were indicated on the monitor such that subjects were told that it was "time to take a rest," and they were told how many trials they would receive in the subsequent trial block. At the end of the experiment, the printed message "THAT'S ALL" was presented on the computer screen.

Procedure. A paired-comparison paradigm was employed for presentation of the 8 chordal stimuli. A condition of the chord presentations demanded that the first stimulus of each pair on a trial was always the same chord. Further, the second chords of each pair could be any one of the 8 stimuli as long as the two were not identical on a trial. When all possible combinations of chords were constructed under these conditions, a total of 448 trials resulted. Each presentation order of trials was randomized for each subject. Subjects were instructed to choose the pair on a trial in which the two chords sounded

Figure 12. Representation of the response-box which appeared on the monitor to remind subjects of the functions of each button. "1st" and "2nd" referred to the buttons which should be depressed if the first or second pair of chords, respectively, was chosen as sounding most similar to one another. "NA" reminded subjects that this button was "not applicable" to any responses to be made in the experiment.

N/A

1st	2nd

"most similar" to each other by depressing the appropriate response button on the response box. Subjects were told that the first chord of each pair within a trial would always be the same, and that this chord was meant to serve as the "standard" chord. They were instructed to make their judgments about the second chord of each pair in relation to this chord. They were strongly encouraged to make their responses immediately after the second pair was presented and to give the "first answer which comes to mind."

Results

Hierarchical Clustering

A preliminary analysis of the similarity judgments for each subject was conducted using a Group Average Hierarchical Clustering technique (Edmonston, 1985). The data matrix for each subject consisted of choice scores, or the number of times each stimulus chord was chosen as sounding similar to each standard chord. Each matrix was arranged in an N x P format, in which N refers to the stimulus chords when they served as the standard chords, and P refers to the stimulus chords when they served as comparison chords. To the extent that standard chords showed similar patterns of choices for comparison chords, these standards would be assumed to have been perceived in a similar manner. Before the cluster analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Euclidean distance formula. The cluster analysis procedure described in Chapter II was then performed on each of these matrices. When the dendrograms which were formed as a result of the clustering were sorted according to the inferred strategies used to judge the chords (either on the basis of root-note or pitch-height), several subgroups of subjects were formed. Of the 42 subjects, 6 appeared to have made their judgements on the basis of root-note (4 professionals; 2 moderately trained; 0 inexperienced); 12 ordered the chords on the attribute of pitch-height and grouped the Shepard chords separately from the other chordal stimuli (1 professional; 4 moderately trained; 7 inexperienced); and 18 ordered all chords, including Shepard chords on the feature of pitch-height (0 professionals; 11 moderately trained; 7 inexperienced). Six subjects were unclassifiable due to an inability on the part of the experimenter to detect a single strategy that each of these subjects might have employed (0 professionals; 3 moderately trained; 3 inexperienced).

Of the six subjects who appeared to judge the similarity of the chords on the basis of root-note, the four professional musicians gave a more orderly result than the moderately-trained musicians, with the A- and E-major triads clearly separated from one another in the resulting dendrograms. Only one of these professionals treated the Shepard chords as a separate entity from the chords comprised of simple tones, but a clear distinction was still made between the A- and E-major sine triads. Figure 13A displays a dendrogram of one of the subjects who joined all the A-major chords as one cluster and all the E-major chords as a separate cluster. As can be seen in the dendrogram, the final linkage connecting each cluster of A- and E-major chords occurred at a fairly high level of dissimilarity relative to the other linkages within each root-note cluster. The results for the other professional musician who treated the Shepard chords as a separate entity, are presented in Figure 13B. This subject's results showed three main groupings of chords: the A-major chords, the E-major

Figure 13. Sample hierarchical clustering solutions from Experiment 1 using Group Average Method.

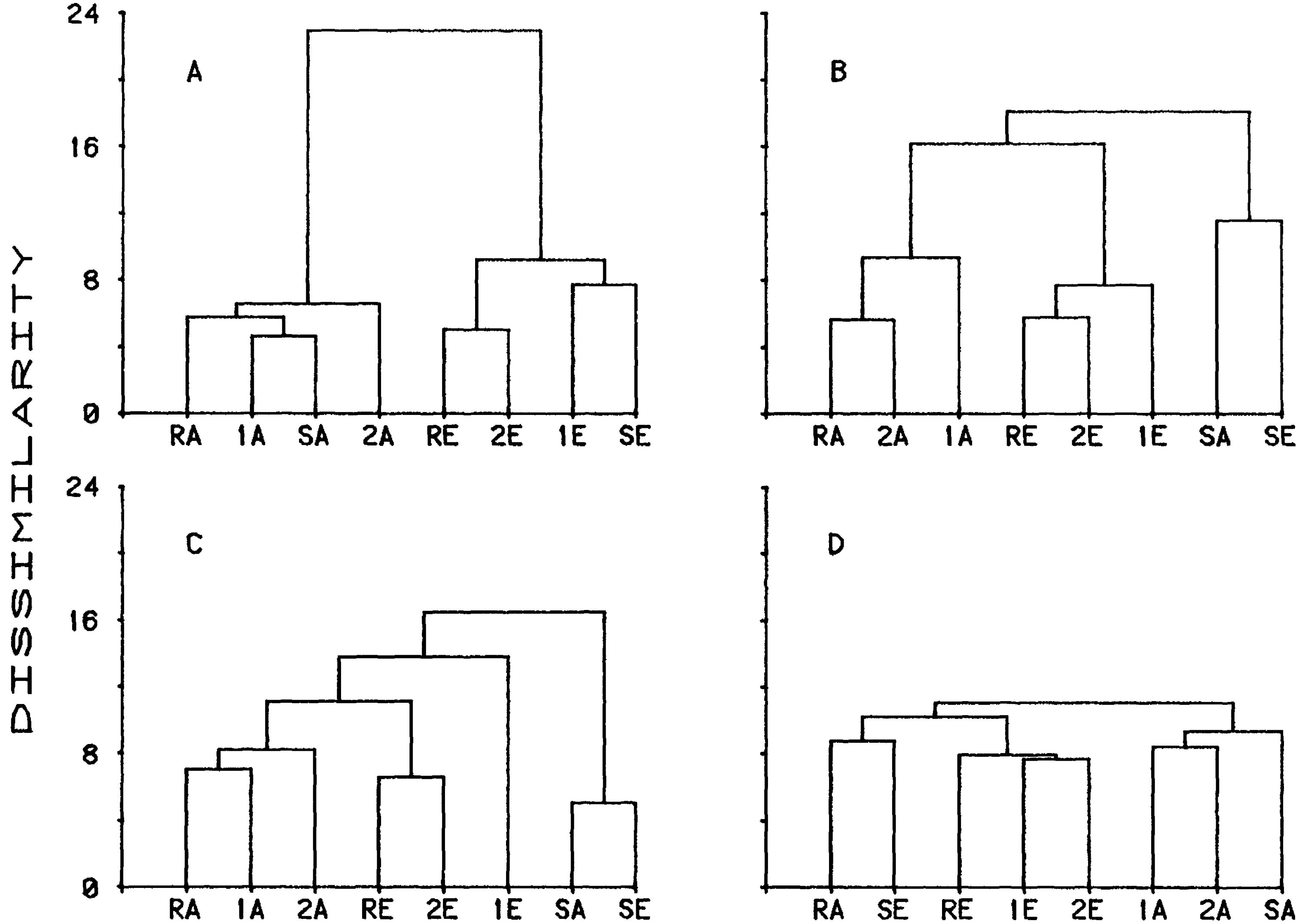
A: Dendrogram for one professional who clustered by root-note.

B: Dendrogram for one professional who clustered by root-note, but treated the Shepard chords as a separate entity.

C: Dendrogram for one moderately-experienced subject who generally clustered by root-note, but treated the Shepard chords as a separate entity.

D: Dendrogram for one moderately-experienced subject who generally clustered by root-note, and generally grouped the Shepard chords with their respective keys.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E= First Inversion E; 2E = Second Inversion E; SA = Shepard A; SE = Shepard E)


DISSIMILARITY
24
16
8
0
A
RA 1A SA 2A RE 2E 1E SE
B
RA 2A 1A RE 2E 1E SA SE
C
RA 1A 2A RE 2E 1E SA SE
D
RA SE RE 1E 2E 1A 2A SA

chords, and the two Shepard chords. The clusters of A- and E-major chords were joined at a high level of dissimilarity, and were then joined as a group by the cluster of Shepard chords.

The results for the two moderately-trained subjects who apparently used a root-note strategy were less clear than for the professionals. There was a tendency for the A- and E-major triads to be separated from one another, although neither subject categorized all four A chords as a separate group from the four E chords. Their results did not appear attributable to a pitch-height strategy, however, and are pictured in the dendrograms displayed in Figures 13C and 13D.

Figure 14A shows a representative dendrogram of one of the 12 subjects who judged the A- and E-major chords on the basis of pitch-height and grouped the Shepard chords separately from the other chordal stimuli. As can be seen in the figure, the two chords lowest in pitch-height (2A and RA) were clustered to each other, and then joined by a cluster of two chords of intermediate pitch-height (2E and 1A). Recall that the 2E and 1A chords were included as flags to a pitch-height strategy. These four chords as a group were then joined by the chords of highest pitch-height (RE and 1E). The two Shepard chords were joined to each other, and were the last to associate with the cluster of all other A- and E-major chords. Such a result could have been obtained because of the distinctive timbral quality of the Shepard chords, or because the Shepard chords were perceived as having a high pitch-height. Eleven of the 12 subjects who ordered the conventional chords on the basis of pitch-height, and grouped the Shepard chords as a separate cluster, showed

Figure 14. Sample hierarchical clustering solutions from Experiment 1 using Group Average Method.

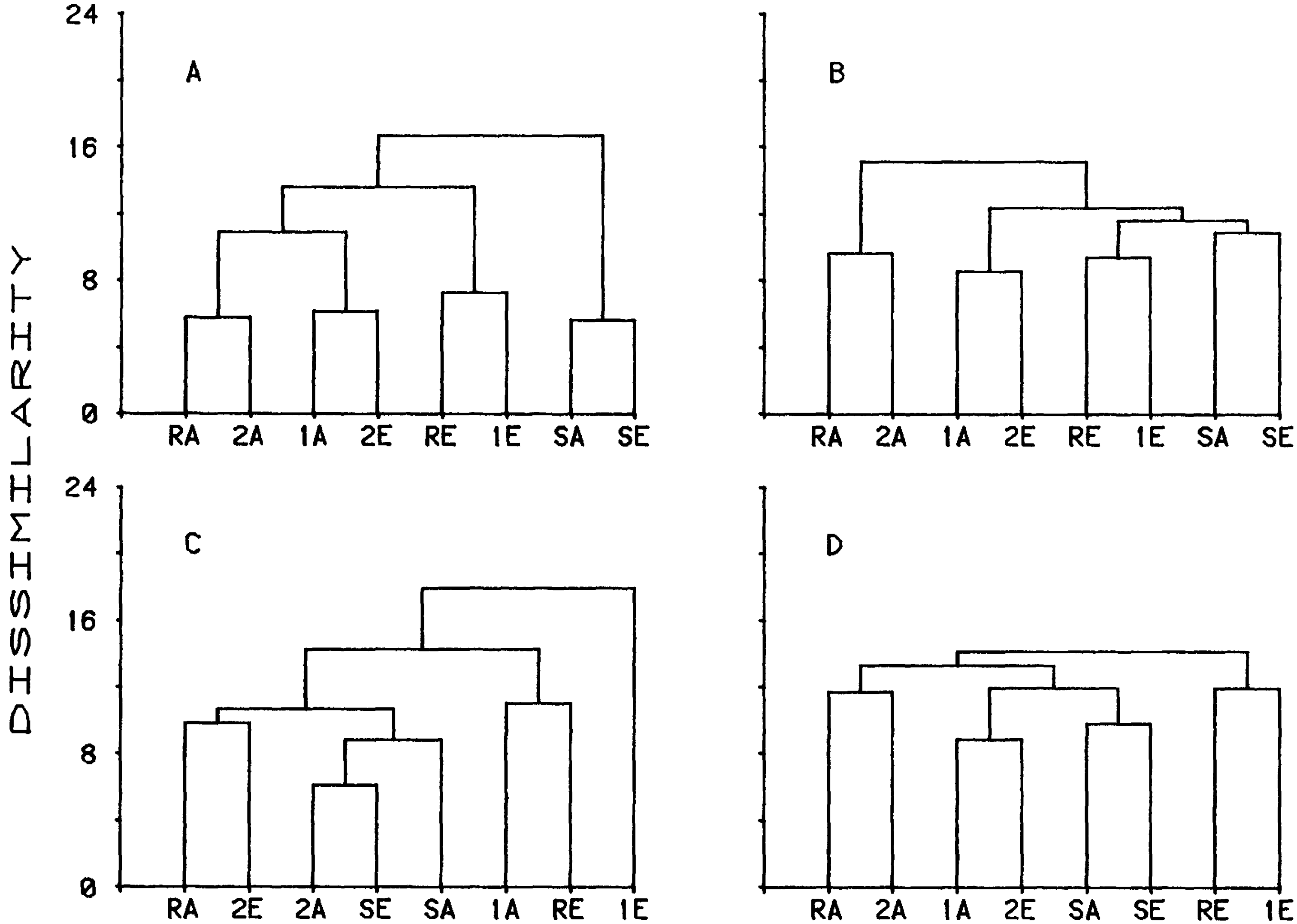
A: Dendrogram for one inexperienced subject who judged the conventional chords on the basis of pitch-height, and treated the Shepard chords as a separate entity.

B: Dendrogram for one moderately-experienced subjects who judged all chords on the basis of pitch-height, and grouped the Shepard chords with the higher-pitched chords.

C: Dendrogram for one moderately-experienced subject who judged all chords on the basis of pitch-height, and grouped the Shepard chords with the lower-pitched chords.

D: Dendrogram for one moderately-experienced subject who judged all chord on the basis of pitch-height, and grouped the Shepard chords with the intermediate-pitched chords.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; SA = Shepard A; SE = Shepard E)


DISSIMILARITY
24
16
8
0
A
RA 2A 1A 2E RE 1E SA SE
B
RA 2A 1A 2E RE 1E SA SE
C
RA 2E 2A SE SA 1A RE 1E
D
RA 2A 1A 2E SA SE RE 1E

dendrograms in which the Shepard chords were linked to the high-pitched chords. The remaining subject linked the Shepard chords with the low-pitched chords. Linkage with the high-pitched chords would be compatible with a "melody-hunting" (Farnsworth, 1938) explanation, especially if the presence of a number of high frequency components was particularly salient for these subjects.

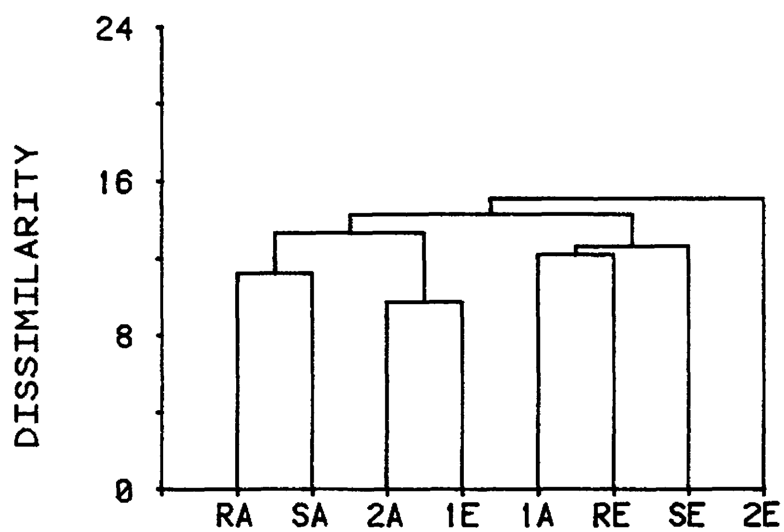
The 18 subjects who ordered all chords, including Shepard chords, by following a pitch-height similarity scheme, were further subdivided depending on whether they treated the Shepard chords as high in pitch-height (2 moderately trained; 5 inexperienced), low in pitch-height (5 moderately trained; 0 inexperienced), or of an intermediate pitch-height (4 moderately trained; 2 inexperienced). A characteristic dendrogram for each of these subgroups is included in Figures 14B, 14C, and 14D. These three dendrograms can be distinguished by whether the SA and SE chords were joined to high-, low-, or medium-pitched chords, as determined by the pitch-height continuum of eight stimulus chords.

Figure 15 shows a dendrogram for one of the subjects labeled unclassifiable. Examination of individual dendrograms within this group yielded no discernible pattern of grouping by pitch-height, root-note, inversion, or Shepard chord.

Regarding groupings by inversion, there were no consistent tendencies across any experience group, except for the professionals, to show a tendency to categorize chords in particular positions as members of the same group. Four of the professionals joined the root chords of each key to the

Figure 15. Sample hierarchical clustering solution from Experiment 1 using Group Average Method showing a dendrogram for one inexperienced subject whose results were unclassifiable.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; SA = Shepard A; SE = Shepard E)


DISSIMILARITY
24
16
8
0
RA
SA
2A
1E
1A
RE
SE
2E

second inversions of their respective keys. This could possibly be explained by Forte's (1979) claim that the second inversion is only equivalent to the root when the root precedes it in presentation. Closer inspection of the raw choice scores by the present author, however, revealed no significant differences in ratings whether the root was presented before or after the second inversion. That is, subjects were equally likely to rate the root and second inversion chords as highly similar regardless of order of presentation.

The clusters obtained for the two professional musicians who claimed absolute pitch were not distinguishable from the other subjects displaying root-note results. One of these subjects had separated the A- and E-major chords from one another, with the A- and E-Shepard chords included with their proper root-note groupings. The other subject separated the A- and E-major chords from one another, but separated the Shepard chords as a distinct entity from the more conventional A- and E-major triads.

If the chordal stimuli had been judged on the basis of relative pitch-heights of the fundamental roots, a predicted clustering might be of the SA and SE chords (fundamental roots = 27.5 Hz and 41.2 Hz, respectively), followed by a linkage of the conventional A-major triads (fundamental root = 110 Hz), and then the conventional E-major triads (fundamental root = 165 Hz). No subject performed in this manner, although it is possible that subjects who separated the Shepard chords from the conventional A- and E-major chords were doing so on the basis of the large discrepancy between frequency of the Shepard chord fundamental roots and the conventional chord fundamental roots. The present author does not put much faith in this explanation, however, since many of the subjects who separated the Shepard chords from the more conventional chords proceeded to order the conventional chords on the basis of pitch-height, and not root-note. If, however, a subject had grouped the conventional chords on the basis of root-note, after separating-out the Shepard chords, it would still not be possible on the basis of this experiment to determine whether this was done because of distinctive timbral quality or fundamental root.

In conclusion, the results of the hierarchical clustering indicated four predominant strategies that subjects used to make similarity judgements. These included: a root-note judgement strategy in which triads built on the same root-note were judged as sounding very similar to one another; a pitch-height judgement strategy in which all chords, including Shepard chords, were judged on the basis of their overall pitch-heights; a root-note strategy in which all chords except for the Shepard chords were judged according to root-note; and a pitch-height strategy in which the chords built with three pure-tone components were judged according to overall pitch-height, but it could not be determined if the Shepard chords were judged on the basis of pitch-height or distinctive timbral quality. For the third and fourth strategies, the Shepard chords were judged as sounding very similar to one another but quite distinct from the triads built with three pure-tone components.

Multidimensional Scaling

The main analysis of this experiment used INDSCAL, an individual differences model in the multidimensional scaling program ALSCAL (Young, Takane, & Lewyckyj, 1978). This model was used to reveal other possible strategies/dimensions on which the subjects could have based their similarity judgements. The data matrix for each subject was organized in a similar manner to those used for the cluster analysis, in an N x P format, with N referring to the stimulus chords when they served as standard chords, and P referring to the stimulus chords when they served as comparison chords. The matrices differed from the clustering matrices in that binary data comprised the entries, rather than the total number of times a comparison chord was chosen as sounding similar to a standard chord. A 0 was entered if the comparison chord of the first pair of chords was chosen, and a 1 was entered if the comparison chord of the second pair was chosen. To the extent that standard chords revealed a similar pattern of choices for the comparison chords, the standards would be assumed to have been perceived in a similar manner. Before the scaling analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Simple Matching measure of binary association. The multidimensional scaling procedure described in Chapter II was then performed on each of these matrices. Figures 16 and 17 depict the solution obtained for 3 dimensions, which accounted for 62% of the variance (S-STRESS = .262; STRESS = .168). In Figure 16 can be seen the dimensions of root-note and pitch-height, which were originally detected in the cluster analysis. The horizontal axis displays the pitch-height dimension, in which the stimulus chords are ordered from high to low pitch-height. The Shepard chords appear to have been judged as having an intermediate pitch-height, relative to the other chordal stimuli. On the vertical axis the root-note dimension is depicted by a separation of all four E-major chords from the four A-major chords.

Figure 16. Two dimensions of the 3-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 1.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; SA = Shepard A; SE = Shepard E)

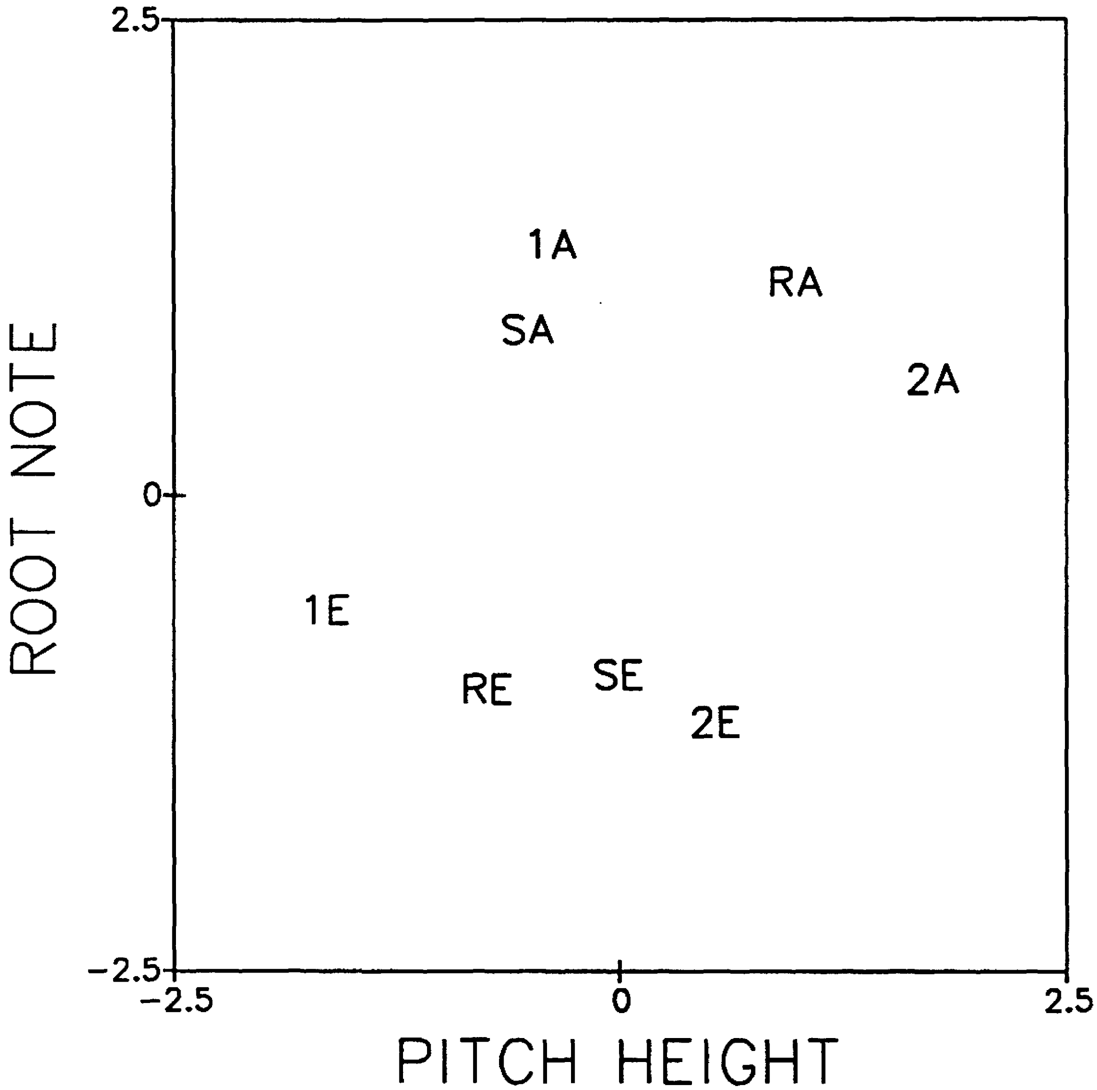
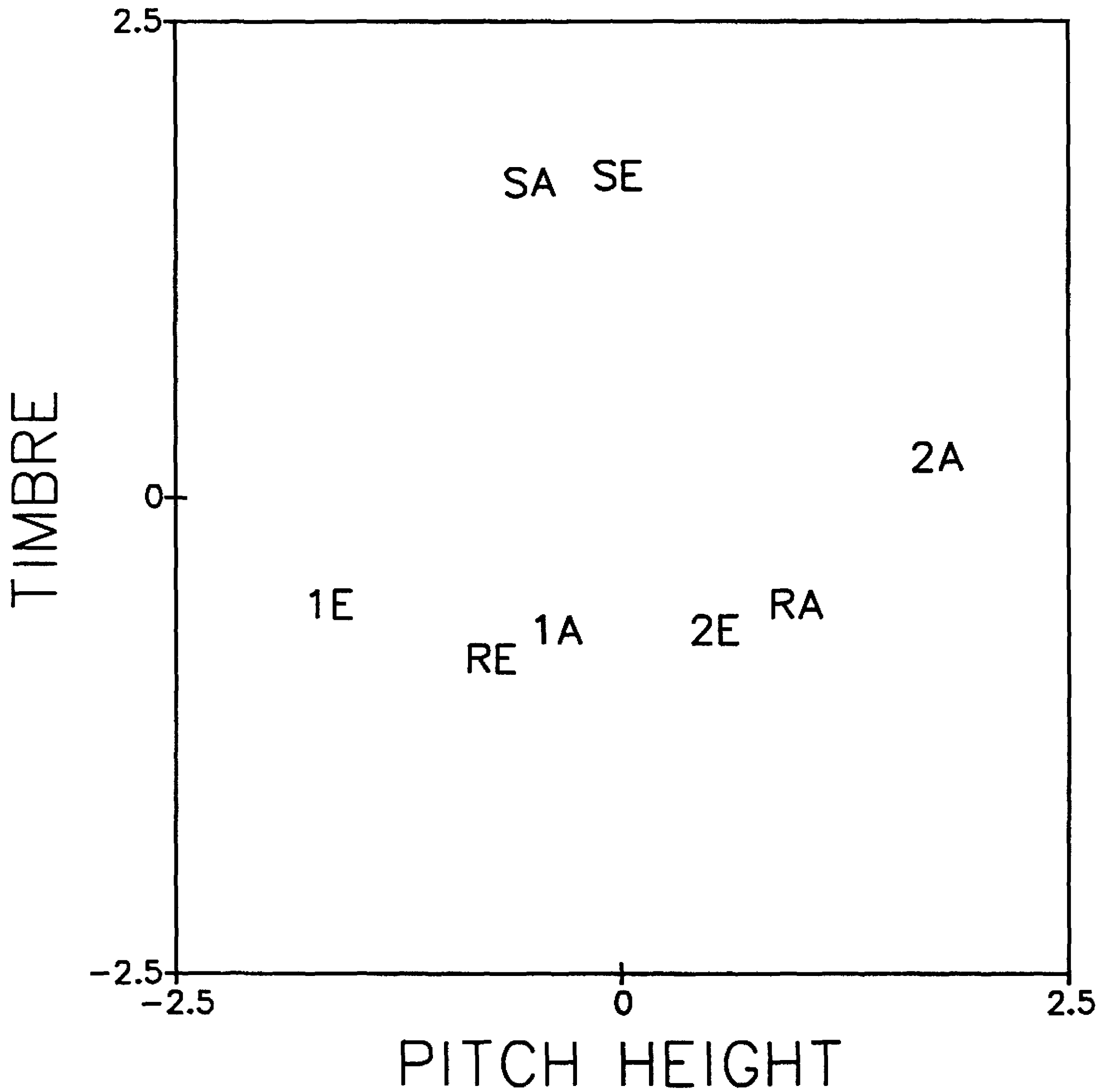

2.5
0
-2.5
-2.5
0
2.5
ROOT NOTE
PITCH HEIGHT
1A
RA
SA
2A
1E
SE
RE
2E

Figure 17. Two dimensions of the 3-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 1.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; SA = Shepard A; SE = Shepard E)


2.5
0
−2.5
−2.5
0
2.5
TIMBRE
PITCH HEIGHT
SA
SE
2A
1E
RE
1A
2E
RA

The third dimension, labelled timbre, is plotted against the pitch-height dimension in Figure 17. The timbre dimension shows a separation of the Shepard chords from the other stimulus chords, a result which was also evident in 14 of the subjects' cluster-analysis dendrograms. The labelling of this third dimension as timbre was for easy reference, and because it is possible that subjects were in fact making a timbral judgment when they separated the SA and SE chords from the more conventional chords. It is possible, however, for subjects who had a tendency to judge the pitch-heights of chords, that these chords were interpreted as high-pitched chords (as possibly shown by one subject's dendrogram in Figure 14A).

Additional information was provided in the multidimensional scaling analysis regarding the subjects' usage of these dimensions which was not afforded by the original cluster analysis. In Figure 18 is presented the derived subject weights for the dimensions of root-note and pitch-height. These weights indicate how strongly a particular dimension predicted a subject's similarity judgements. As can be seen in the figure, the more musically-experienced subjects tended to use a root-note judgement scheme, while approximately half of the moderately-trained and half of the inexperienced subjects relied on assessments of pitch-height. Moderately-trained and inexperienced subjects who did not have particularly high weightings for either dimension were found to either not be fit very well by the model, as indicated by low individual RSQ values, or were found to have particularly high weightings on the dimension of timbre, relative to the dimensions of pitch-height and root-note.

In Figure 19 is shown the derived subject weights for the timbre

Figure 18. Derived subject weights for two dimensions of the 3-dimensional INDCAL solution of Experiment 1.

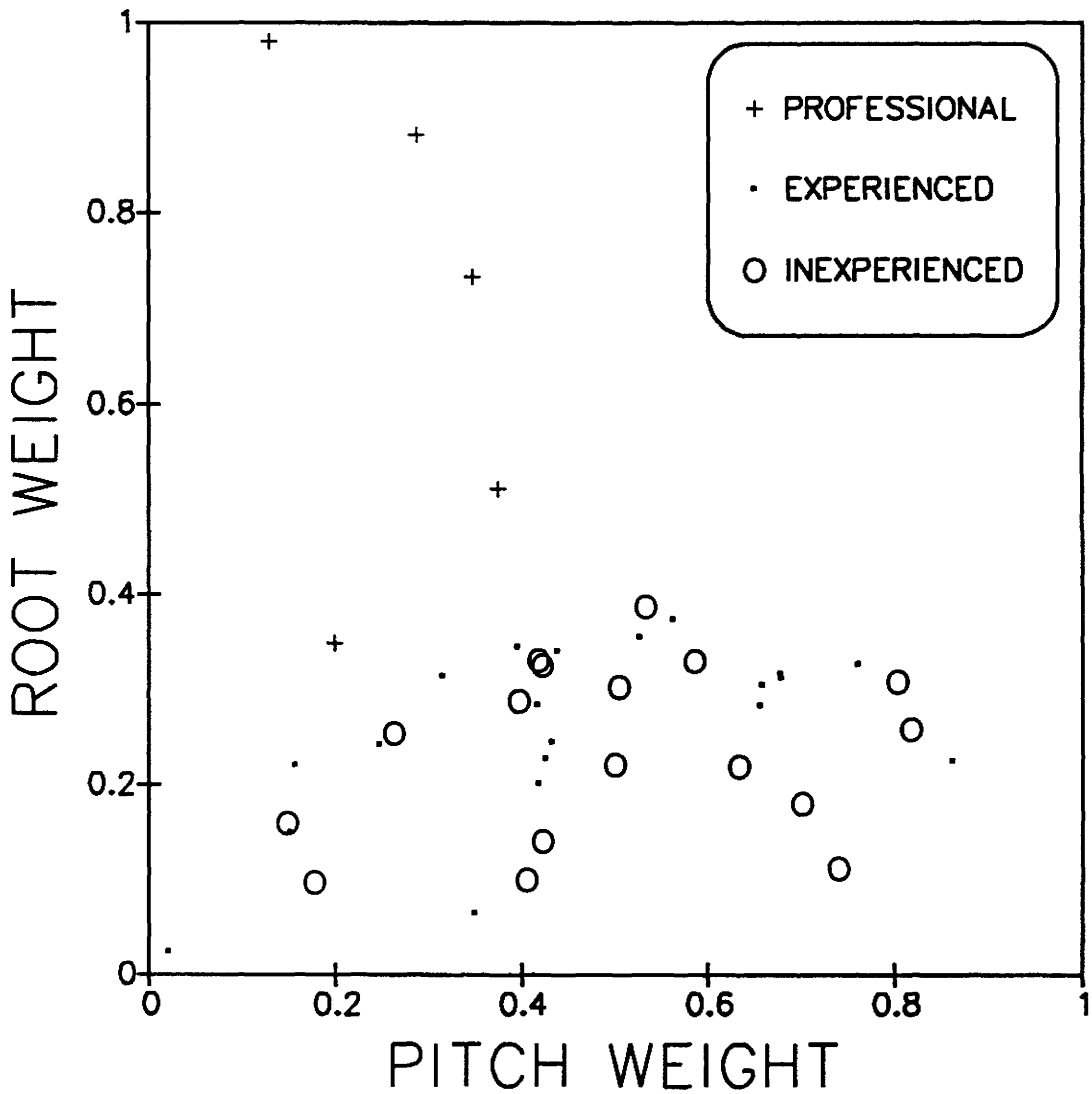
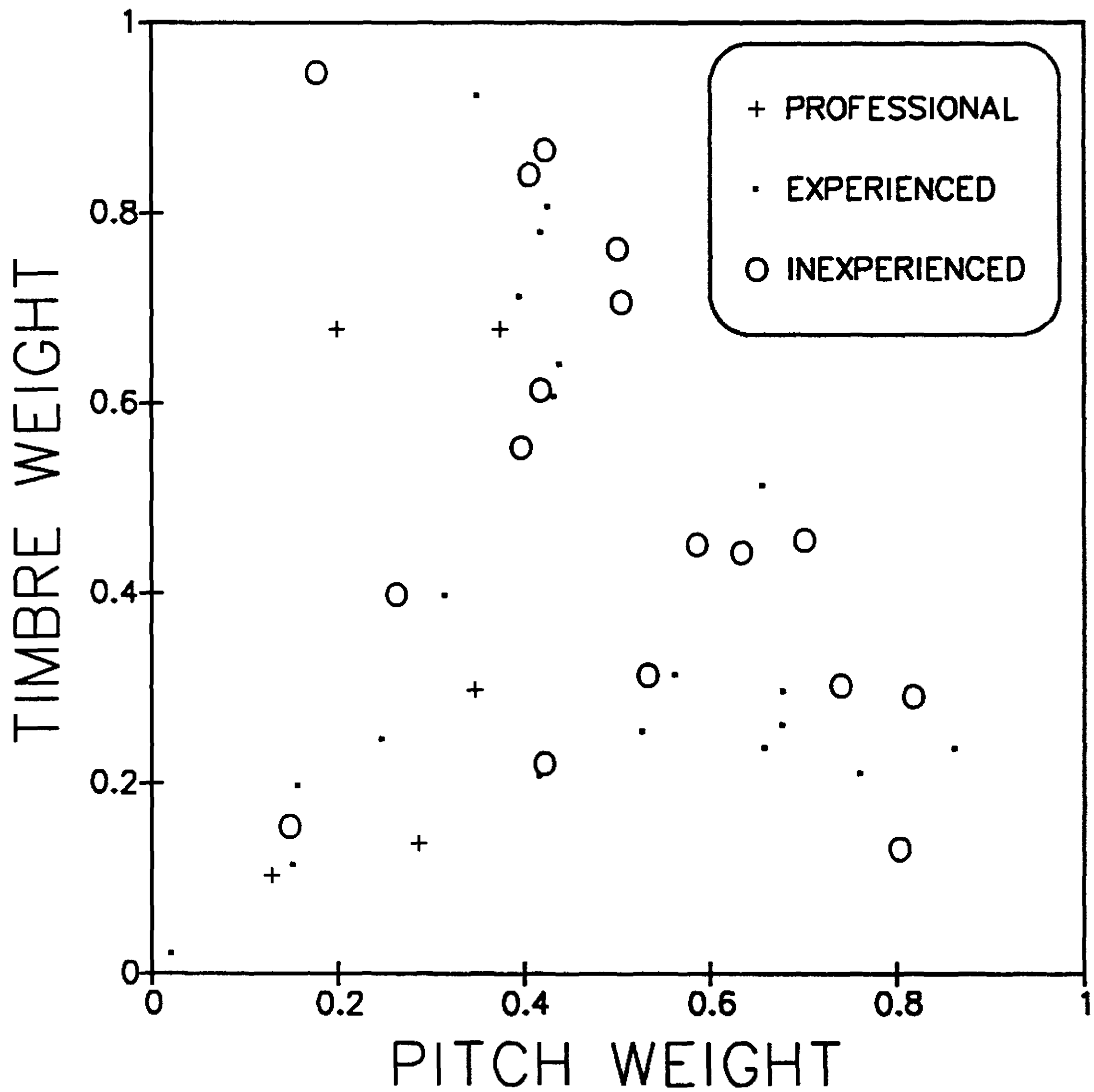

ROOT WEIGHT
PITCH WEIGHT
+ PROFESSIONAL
· EXPERIENCED
O INEXPERIENCED
0
0.2
0.4
0.6
0.8
1

Figure 19. Derived subject weights for two dimensions of the 3-dimensional INDCAL solution of Experiment 1.

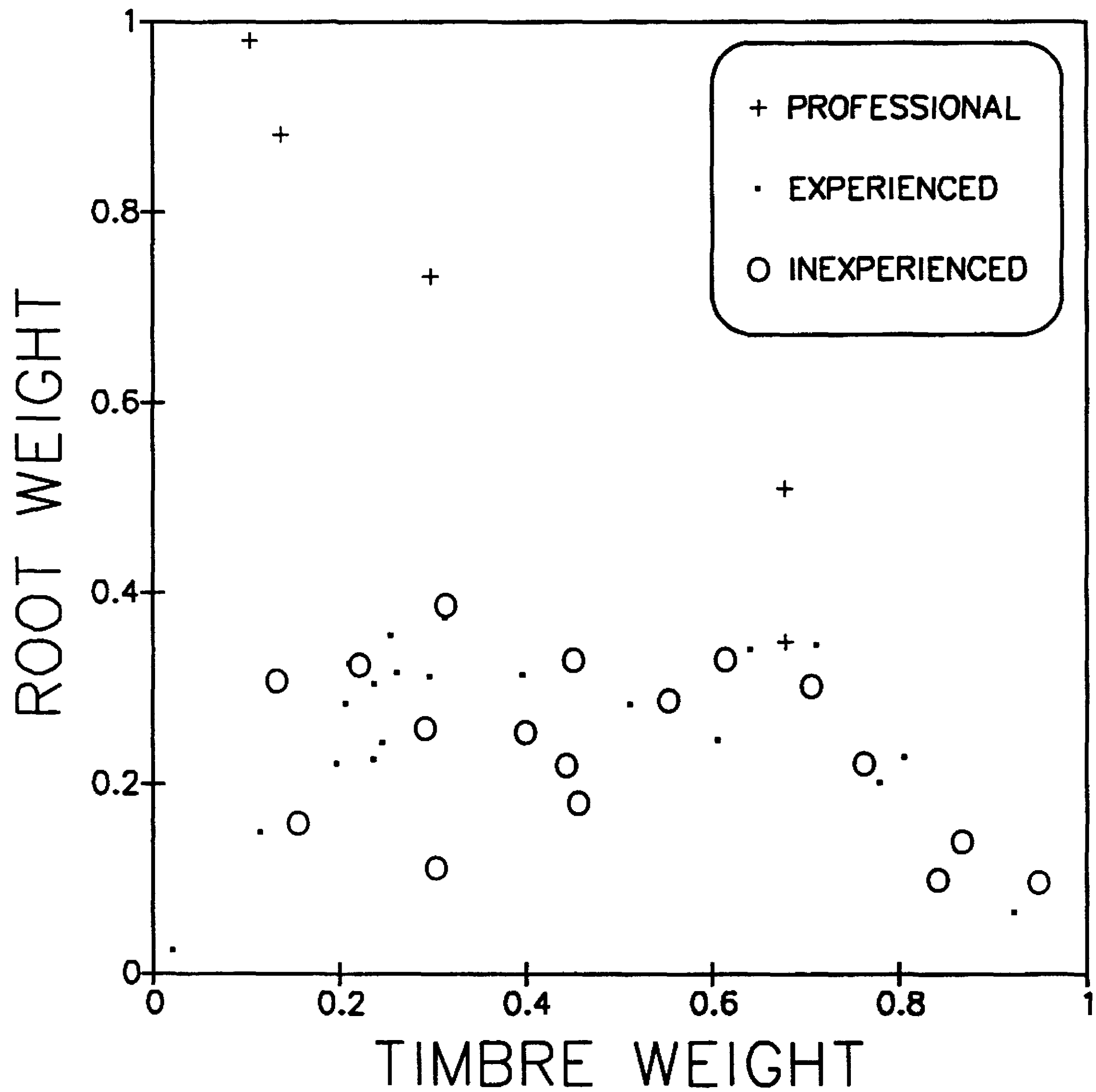


TIMBRE WEIGHT
PITCH WEIGHT
0
0.2
0.4
0.6
0.8
1
+ PROFESSIONAL
· EXPERIENCED
O INEXPERIENCED

dimension against that of pitch-height. Approximately one-half of the moderately-trained and one-half of the inexperienced subjects had high weightings on the pitch dimension relative to the timbre dimension. Most of the remaining subjects in these two groups weighted highly on timbre, but low on pitch-height. Closer inspection of the actual subject weights for these high-timbre/low-pitch subjects revealed that these subjects had their highest weights on the dimension of timbre, followed by pitch-height, and finally root-note. The two professionals who also displayed high weights for the timbre dimension relative to pitch-height, also had their highest weightings for the timbre dimension, but their second highest weightings were for the dimensions of root-note, followed by pitch-height. The remaining three professionals, along with a few moderately-experienced and inexperienced subjects, had low weightings on both pitch-height and timbre. These subjects either had very high weights on the dimension of root-note, or their data were not accounted for very well by the model, as indicated by low RSQ values.

In Figure 20 is shown the derived subject weights for the root-note dimension against the dimension of timbre. It is evident that the professionals weighted most heavily on the dimension of root-note, with a tendency for two of the professional subjects to also be influenced by the distinctive timbral quality of the SA and SE chords. A number of the moderately-trained and inexperienced subjects, along with one professional, weighted heavily on the timbre dimension, but not on that of root-note. Subjects not weighting heavily on either of these dimensions tended to be either those whose weights were substantially higher on the dimension of pitch-height relative to their weights

Figure 20. Derived subject weights for two dimensions of the 3-dimensional INDCAL solution of Experiment 1.


+ PROFESSIONAL
· EXPERIENCED
O INEXPERIENCED
ROOT WEIGHT
TIMBRE WEIGHT
0
0.2
0.4
0.6
0.8
1

for root-note and timbre, or those whose overall variance was not accounted for very well by the model.

Discussion

The results of this experiment supported the theoretic notion that major tonic triads can instantiate a sense of key, and that triad inversions can be perceived as harmonically equivalent with respect to key, if highly-trained musicians are asked to judge them. Four of the 5 professionals, along with 2 of the 20 moderately-experienced musicians, based their judgements on the root-notes of the triads, indicating the A-major chords to be very similar to one another, and the E-major chords to be very similar to one another, but for the 2 groups of chords to be very different from one another. Given the multiple harmonic functions shared between these two keys, and the level of musical training attained by the subjects who exhibited root-note judgements, it would appear that it takes a very highly-skilled individual to distinguish between highly-related chords, with no other cues to musical key than the triads themselves. The remaining subjects, which included a group of musically-untrained individuals, either based their judgements on the overall pitch-heights of the triads, or their results were uninterpretable. That the subjects who appeared to use a pitch-height strategy displayed chord-groupings similar to the pre-determined pitch-height ordering of stimulus chords, supports the interpretation that these subjects attended to the pitch-heights of the higher chordal components, regardless of whether these components functioned as roots, thirds, or fifths.

The finding that perception of the root-notes of the chords superseded differential perception of chord position, was taken as supportive of the perceived equivalence between roots, first inversions, and second inversions for the most highly-trained musicians. If these chord positions had obeyed the laws of ordering proposed by Rosch (1975) for prototypical entities within a category, then one would have expected that when the root-chord was the first stimulus of the pair, in the "standard" position, that chords more stable with regard to the root would have been chosen more often than those which are theoretically less stable. That is, the root would have been chosen most often when paired with itself, followed by the first inversion, and then the second inversion.

Regarding the use of Shepard chords, it was hoped that these would serve as a device for encouraging all subjects, regardless of training, to use a chroma judgement scheme. One would have expected, given the claims of Shepard (1964) and Krumhansl, Bharucha, and Kessler (1982), that these chords would have greatly attenuated the effects of inversion and pitch-height, leaving only a strong sense of tonality as their main quality. Only a few highly-experienced subjects, however, judged them on the basis of their respective keys. A fair number of subjects appeared acutely aware of the distinctive timbral quality of these two chords, and often separated them from all other chordal stimuli, although a pitch-height interpretation cannot be discarded on the basis of the present data (see for example, Figure 14A). Other subjects judged the Shepard chords on the basis of pitch-height, but results varied with respect to whether the Shepard chords were treated as being of high pitched, low pitched, or of some intermediate pitch. Not finding more subjects who judged the chords on the basis of their root-notes could have been a function of too little musical context, a lack of subjects' musical experience, or the distinctive timbral quality of the chords which was enhanced by including them in the context of an experiment where chords built in a more conventional manner were also presented.

It had been questioned whether subjects could make their similarity judgements by hearing-out the fundamental roots of the chords, and then judge the chords on the basis of the pitch-heights of the fundamentals. This was possible for any subject who separated the Shepard chords, which had the lowest fundamental roots, from the A-major chords, which had intermediate roots, from the E-major chords, which had the highest fundamentals. Two subjects performed in this manner, but it cannot be determined whether they judged the chords on the basis of differential fundamental roots, or on the basis of root-note, with the Shepard chords supposedly separated because of their distinctive timbral qualities.

The instruction to judge "similarity" of the triads was made purposely ambiguous with respect to any particular chordal dimension. The data for one professional musician, whose primary instrument was voice, did not clearly indicate judgements with respect to pitch-height, root-note, or inversion, although she was classified as a pitch-height subject because of a tendency to judge the chords on the basis of pitch-height. During the experimental session this subject had expressed a concern as to what the experimenter had meant by judging "similarity" of chords, and had questioned whether it was root-note or pitch-height that was the desired dimension. In an effort to more clearly delineate what type of strategy this subject was utilizing, and to possibly induce her to produce results like those of the other highly-trained subjects, she was run in the experiment a second time, but was given a more explicit set of instructions. This second time, she was told to judge the similarity of the chords on the basis of root-note, and that if both chords possessed the same root-note, she should then choose the pair of chords of which she felt most certain were most similar. Her results in this second session with the less ambiguous instructions became even more difficult to interpret, although pitch-height appeared to be the most likely strategy.

This subject's main instrument was voice, and it has been a common practice in recent years among those working in music laboratories to exclude vocalists from their studies. This is due to the prevalent lab-lore that there is something different about the way these individuals process music in comparison to instrumentalists. It is perhaps because vocalists must actually generate the sound "from within," coordinate this sound with other voices and/or instruments, and deal with such aspects of performance as bone conducted feedback, unlike instrumentalists, that has made many of their results uninterpretable. Even when the vocalist of the present study was given more precise instructions and run in the experiment a second time, a more comprehensible pattern of results could not be determined, indicating that the result was not manipulable with verbal instructions.

Conclusion

The results for four of five professional musicians appeared to support the previous finding of a well-structured hierarchy for chord functions.

In the absence of a rich musical context, these highly-trained subjects treated isolated triads as musical entities, making similarity judgements on the basis of root-note. It is noteworthy that chords from maximally-related keys were so strongly separated by these subjects, as indicated by the high levels of dissimilarity between keys in the dendrograms. This finding is quite different from the majority of moderately-trained subjects and all of the inexperienced ones, who tended to judge the chords on the basis of pitch-height, and can probably be attributed to the high levels of training attained by the professionals. This result also supported proposals made by others that a sensible pattern of results, in terms of hierarchies of chordal functions for isolated triads, could be found only in very highly skilled musicians (Roberts and Shaw, 1984). It is concluded, therefore, that with more advanced skill levels comes the ability to access the hierarchy automatically in the absence of elaborate musical cues.

One possible reason that the majority of less-experienced subjects did not exhibit judgements indicative of sensitivity to inversion or root-note, could be that their training had not been extensive enough to switch from processing isolated triads in a "psychoacoustic" mode, in which they attended to pitch-height, to a "musical" mode, in which they attended to root-note. Only the most highly-trained subjects differentiated the triads on the basis of root-note, reminiscent of the Roberts and Shaw (1984) study in which they could not determine a sensible pattern of results for subjects with less than 10 years training, some piano background, and at least 2 years of theory. It is possible that there exists an interaction of musical context and experience, whereby those with more musical training do not require as much musical context to process a sound in a musical manner. One possible way to test for this interaction, and to obtain choice patterns reflecting a hierarchical structuring for chordal functions in moderately-trained subjects, would be to provide a greater amount of musical context to encourage judgements of the chords as musical elements. The inexperienced subjects' pitch-height results, however, would be anticipated to be of a similar nature even with provision of a stronger musical context, given the results of other experiments which had established substantial contextual cues, such as scales or cadences, and found that these less-trained subjects often used a pitch-height strategy (e.g., Krumhansl & Shepard, 1979).

The purpose of Experiment 2 was to test whether provision of a more musical context could entice a greater number of moderately-trained subjects to judge the triads on the basis of root-note. The subjects in Experiment 1 had had a substantial amount of training (mean years lessons = 7.3), and would be expected to have some cognizance of the workings of the hierarchy of musical functions. In order to adhere to the belief that major triads are capable of instantiating key, this additional musical context was provided in the form of major triads drawn from a key maximally distant to the A- and E-major triads. A similar paradigm to Experiment 1 was used, in which triads from a maximally-distant key were presented in addition to the A- and E-major triads. In this way, if the multiple harmonic functions between the A- and E-major triads had been a source of confusion as to the desired judgement dimension, then provision of a maximally distant key should make it obvious that the desired dimension is musical key, or more precisely, root-note.

CHAPTER IV

EXPERIMENT 2

Judgements of major triads on the basis of root-note in the absence of an elaborate musical context was obtained only in very highly-trained musicians in Experiment 1, and it seemed desirable to test the contextual factor of the hypothesized Musical Context by Experience interaction, by manipulating the musical context in which the triads of the judgement task were presented. In this way, the chords might be more readily interpreted as musical events, rather than isolated sounds to be judged on a psychoacoustical dimension such as pitch-height. Providing this additional context might encourage subjects with less-advanced musical training to judge the triads on the basis of root-note, even when these triads were drawn from maximally-related keys.

One possible explanation for the lack of a root-note strategy for the moderately-trained subjects in Experiment 1 might be the multiple harmonic functions shared between the keys presented to them. In Experiment 1, the maximally-related keys of A and E major were the only context provided in the experiment. These keys share all but one note and four of a possible seven chords, which could have served as a source of difficulty in differentiating between them. In addition, several of the chords and tones common to the two keys are considered highly stable and central to both tonalities. The E-major tonic triad (I) is built on the fifth degree (V) of the A-major scale, and the tonic

A-major triad (I) is built on the fourth degree (IV) of the E-major scale. According to music theoretic principles, the most important major chords are the tonic (I), followed by the dominant (V), and then the subdominant (IV). When these three triads are presented in conjunction with one another, a strong sense of key is established, because together they contain all the notes of the major diatonic scale from which they are built (Randel, 1978). Empirical evidence showing that these three chords are perceived to be the most stable of all the diatonic triads has also been obtained (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982). Because these highly stable chords were shared between the two keys of Experiment 1, it is easy to see how it might have been difficult to judge the keys as separate tonal units. Furthermore, this might have been a particularly difficult task for the moderately-experienced subjects, who might not yet possess the firmly established chordal hierarchy upon which professional musicians could draw to make their chordal judgements.

In keeping with the belief that major triads are musical entities in their own right, it should be possible to elicit groupings by root-note without resorting to presentations of very elaborate musical constructions such as melodies, scales, and cadences. One way to achieve this would be to continue presenting only triads within the context of an experiment, but to vary the degree of relatedness between the different keys. For example, the two maximally-related A- and E-major chords used in Experiment 1, along with a set of chords maximally distant from the triads of A and E major, could be judged under the same conditions as in the earlier experiment. In this way, it should become obvious to the subjects that the desired rating dimension is musical key, or root-note. This is only predicted to happen, however, if in fact a subject possesses an internal representation of these chordal functions. Experienced subjects, even those with only a moderate level of training, would be expected to possess this underlying representation, whereas inexperienced subjects probably would not, and would therefore continue to resort to the only means which they had to judge the chords--pitch-height.

A number of studies have provided evidence that the Circle of Fifths correctly characterizes the underlying representation of tonal and chordal functions in musically-experienced individuals. Chord similarity ratings have tended to produce an orderly pattern of results in which keys close together on the Circle of Fifths are rated as more similar than those a greater distance apart (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982; Krumhansl & Kessler, 1982), and more errors have been incurred when subjects attempted to identify a changed chord in a sequence when that chord was chosen from a maximally-distant key (Krumhansl & Castellano, 1983). All these experiments provided some form of musical context which could have influenced the manner in which the triads were processed.

It has been shown that major triads can instantiate key, in that greater separations of key occur for more distantly-related keys, and that these separations occur for both close and far keys in moderately-experienced subjects if a musical context is provided (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982; Krumhansl & Castellano, 1983; Krumhansl & Kessler, 1982). Similar patterns of separation occur in the absence of a musical context only for very musically- advanced subjects (Experiment 1; Roberts & Shaw, 1984), and for less-experienced subjects under conditions where only two maximally-distant keys are presented (Bharucha & Krumhansl, 1983). Given these findings, it should be possible to have subjects judge the similarities between keys (i.e., triads built on root-notes which serve as the tonics of their respective keys), which are of different degrees of relatedness within the context of a single experiment, and thereby obtain choice patterns reflecting key distance around the Circle of Fifths. This was the idea to be tested in Experiment 2. In this experiment, a two-alternative forced-choice paradigm was used, as in Experiment 1, to present chords from two maximally-related keys, A major and E major, and one maximally-distant key, Bb major. The key of Bb major shares only two scale tones with A major and two with E major. There are no chords in common between Bb major and the two keys of A and E major.

The root, first inversion, and second inversion positions of each chord were presented in a continued effort to test for inversion effects. The Shepard chords were eliminated from this study, given that all but the most highly-experienced subjects in Experiment 1 judged them on timbral or pitch-height differences, and not with respect to chroma. Krumhansl and her associates (Bharucha & Krumhansl, 1983; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharucha, & Kessler, 1982; Krumhansl & Castellano, 1983; Krumhansl & Kessler, 1982) had obtained chroma ratings (i.e., ratings with respect to key) by using Shepard chords, but they did not also include chords in their experiments which retained their pitch-heights and inversions, as in Experiment 1. Such a variety of chords within the context of one experiment may have highlighted the distinctive sound qualities of the two chord types.

In Experiment 1, chords were tuned to a just scale, but in order to accomodate the more distant key in the present study, equal temperament was used.

In Experiment 2, subjects of three musical experience levels, professional musicians, moderately-trained musicians, and musically-inexperienced individuals, were tested. The professionals were expected to continue their usage of a root-note strategy, while a greater proportion of the moderately trained were expected to now employ a root-note strategy. The inexperienced subjects were expected to continue with their strategy of pitch-height judgements.

Method

Subjects. Forty-four individuals were recruited to serve as voluntary subjects. Five were professional musicians, whose names were provided by the Hamilton Arts Council, Hamilton, Ontario; 1 was a music major in the McMaster University Department of Music; 37 were enlisted from an undergraduate introductory psychology course; and 1 was the experimenter herself. The subjects were grouped according to three experience levels: professional musicians, moderately-trained musicians, and those who were musically inexperienced. The professional group, which was extended to include 1 undergraduate music major, was comprised of 6 individuals, 5 for whom performance and/or teaching was a substantial source of income. Each ranged from 9.0 to 18.0 years on their self-designated primary instruments (mean = 12.0 years). Five of these subjects reported extensive theory training, which included upper level conservatory and university courses, and 4 of the subjects played more than one instrument. Current musical involvement in the form of playing one's primary instrument, teaching, and studying music was reported at an average of 34.0 hours per week, while mean listening activity was reported at 1.5 hours per day. Five of the 6 professionals reported family members who at some time played a musical instrument. Only 2 of the subjects reported having absolute pitch. Of these 6 subjects, 4 were male and 2, female.

The 18 subjects designated moderately trained were recruited under the same requirements for participation as stated in Experiment 1. The training of these 18 subjects ranged from 3.0 to 13.0 years on their self-designated primary instruments (mean = 8.2 years). Sixteen of the 18 subjects reported theory training (mean level attained = 2.4 years), and 16 of the subjects played more than one instrument. Seventeen of these subjects also reported participation in other musical activities such as band and choir at some time during their music studies. Current musical involvement in the form of playing one's primary instrument was reported at an average of 5.1 hours per week, while mean listening activity was reported at 2.3 hours per day. Sixteen of the 18 moderately-trained subjects reported family members who were at sometime involved with music. Of the 18 moderately-trained subjects, 3 were male and 15, female.

The remaining 20 subjects were classified as musically inexperienced. These subjects had responded to requests for subjects who had never had any formal instrumental training nor had been self-taught to play an instrument. Ten of these 20 subjects reported singing in a choir at sometime in their lives, but their participation was minimal. These subjects reported a mean of 2.3 hours per day spent listening to music. Nine of the 20 inexperienced subjects reported familial involvement with music. Within this group 7 were male and 13, female.

One professsional subject, three moderately-experienced subjects, and two inexperienced subjects reported minor hearing losses in one or both ears. Because of the nature of the judgement task (a two-alternative forced-choice task with stimuli presented binaurally at a comfortable level), this was not expected to affect the results of these subjects. All other subjects reported normal hearing.

Apparatus. All apparatus was the same as Experiment 1.

Stimuli. Each trial consisted of the presentation of two pairs of chords. All tones comprising the chords were sine waves and were of equal temperament.

Chords presented in this experiment included the identical A-major and E-major chords in root, first inversion, and second inversion positions used in Experiment 1. In addition, analogous positions were constructed for Bb-major chords built on the tonic (I) tone of that scale, resulting in a Bb-major root chord (Bb: 466.2 Hz, D: 587.3 Hz, F: 698.5 Hz), first inversion (D: 587.3 Hz, F: 698.5 Hz, Bb: 932.3 Hz), and second inversion (F: 349.2 Hz, Bb: 466.2 Hz, D: 587.3 Hz). The first inversion A (1A), second inversion E (2E), and root Bb (RBb) were purposely selected to be constructed of those frequencies because of the extremely close pitch proximities of their component tones. In this way, it was hoped that these three chords would serve as a flag for subjects selecting chords on the basis of pitch-height and not root-note or inversion. That is, if a subject consistently chose these three chords as sounding very similar to each other, one could be fairly confident that they were judged on the basis of pitch-height and not some other stimulus attribute, such as root-note or inversion, because these three chords were of different inversions and root-notes, but were very similar in pitch-height. (See Figure 21A for a diagram of the stimulus chords in the order of increasing pitch-height, and Figure 21B for the musical notation of the stimulus chords grouped on the basis of common root-note.)

The sampling rate for all nine stimulus chords was 20,000 Hz. To prevent aliasing, a low-pass filter cutoff was set at 10,000 Hz. Rise and fall times were set at 50-msec. Measurement with an artificial ear and SPL meter indicated the A-major, E-major, and Bb-major root, first inversion and second inversion chord presentations to be at 75±1 dB SPL. The fundamental root was 110 Hz for the A-major chords, 165 Hz for the E-major chords, and 116 Hz for the Bb-major chords. All duration parameters for the presentation of the chords were the same as Experiment 1. Furthermore, the configurations and instructions presented on the monitor were identical to the earlier study.

There were four trial blocks. Subjects received a 5-min break from the experiment between the first and second blocks, and between the third and fourth blocks. A 30-min break was given between trial blocks two and three.

Procedure. All procedural details were identical to Experiment 1

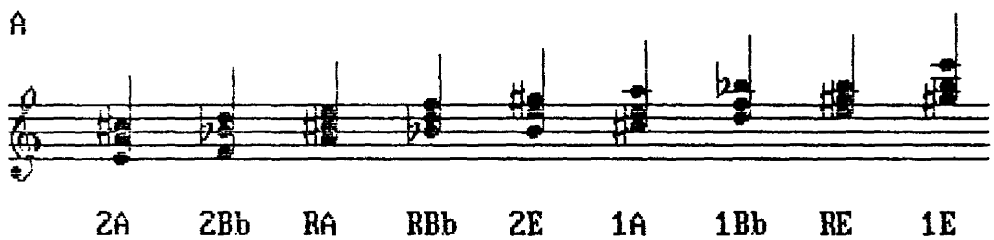
Figure 21. Musical notation of stimuli used in Experiment 2.

A: Triads presented in order of increasing pitch-height.

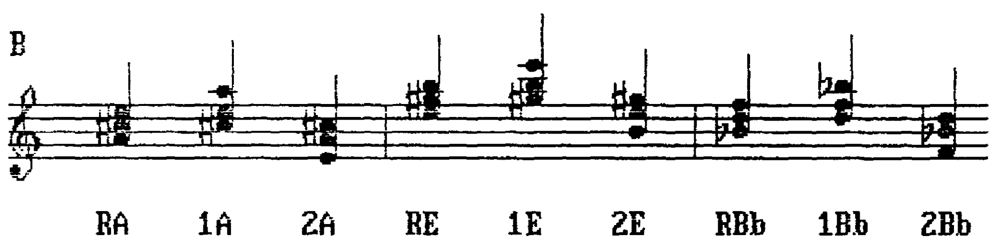
B: Triads grouped by common root-note.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; RBb = Root Bb; 1Bb = First Inversion Bb; 2Bb = Second Inversion Bb)

A



B



with the exception that 9 chordal stimuli were now utilized in the paired-comparison paradigm, resulting in a total of 648 trials. Also, the last 8 subjects run in the experiment were presented with an additional instruction. This instruction brought to their attention that the presentation of identical chord pairs on a trial was considered to indicate maximal similarity. A clarification was considered necessary after one of the subjects expressed concern over the absence of a third response button on the response box to indicate identity.

Results

Hierarchical Clustering

The similarity judgements for each subject were analyzed through the same Group Average Hierarchical Clustering technique (Edmonston, 1985) used in Experiment 1. The data matrix for each subject consisted of choice scores, or the number of times each stimulus chord was chosen as sounding similar to each standard chord. Each matrix was arranged in an N x P format, in which N refers to the stimulus chords when they served as standard chords, and P refers to the stimulus chords when they served as comparison chords. To the extent that standard chords showed similar patterns of choices for comparison chords, those standards would be assumed to have been perceived in a similar manner. Before the cluster analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Euclidean distance formula. The cluster analysis procedure described in Chapter II was then performed on each of these matrices. The resultant dendrograms were categorized on the basis of patterns which suggested either pitch-height or root-note judgements of the triads. Of the 44 subjects tested, 6 separated the chords of all three keys from one another, including the A-major chords from the E-major chords, with a particularly strong separation of the A- and E-major chords from the Bb-major chords (4 professionals; 2 moderately experienced; 0 inexperienced); 6 used a root-note strategy in which there was a strong separation between chords in the keys of A and E major from those of Bb major, but not between the A- and E-major chords (1 professional; 5 moderately experienced; 0 inexperienced); 30 appeared to utilize a pitch-height strategy (1 professional; 9 moderately experienced; 20 inexperienced); and 2 were unclassifiable due to an inability of the experimenter to detect a single judgement strategy that these subjects might have been using (0 professionals; 2 moderately experienced; 0 inexperienced). Four dendrograms were selected as representative of each of these strategies, and are presented in Figures 22A, 22B, 22C, and 22D.

One of the subjects reporting absolute pitch exhibited a pitch-height result, and the other separated the A- and E-major chords from the Bb-major chords without making any clear delineations between the A- and E-major chords.

The six subjects reporting hearing losses showed results that were typical for their experience category. Both of the inexperienced subjects and one of the moderately-trained subjects who reported hearing losses, showed a characteristic pitch-height result. Another moderately-experienced subject with hearing difficulty separated the A- and E-major chords from Bb-major chords, but did not separate the A- and E-major chords from each other. Finally, the one professional subject and the last moderately-experienced subject with a

Figure 22. Sample hierarchical clustering solutions from Experiment 2 using Group Average Method.

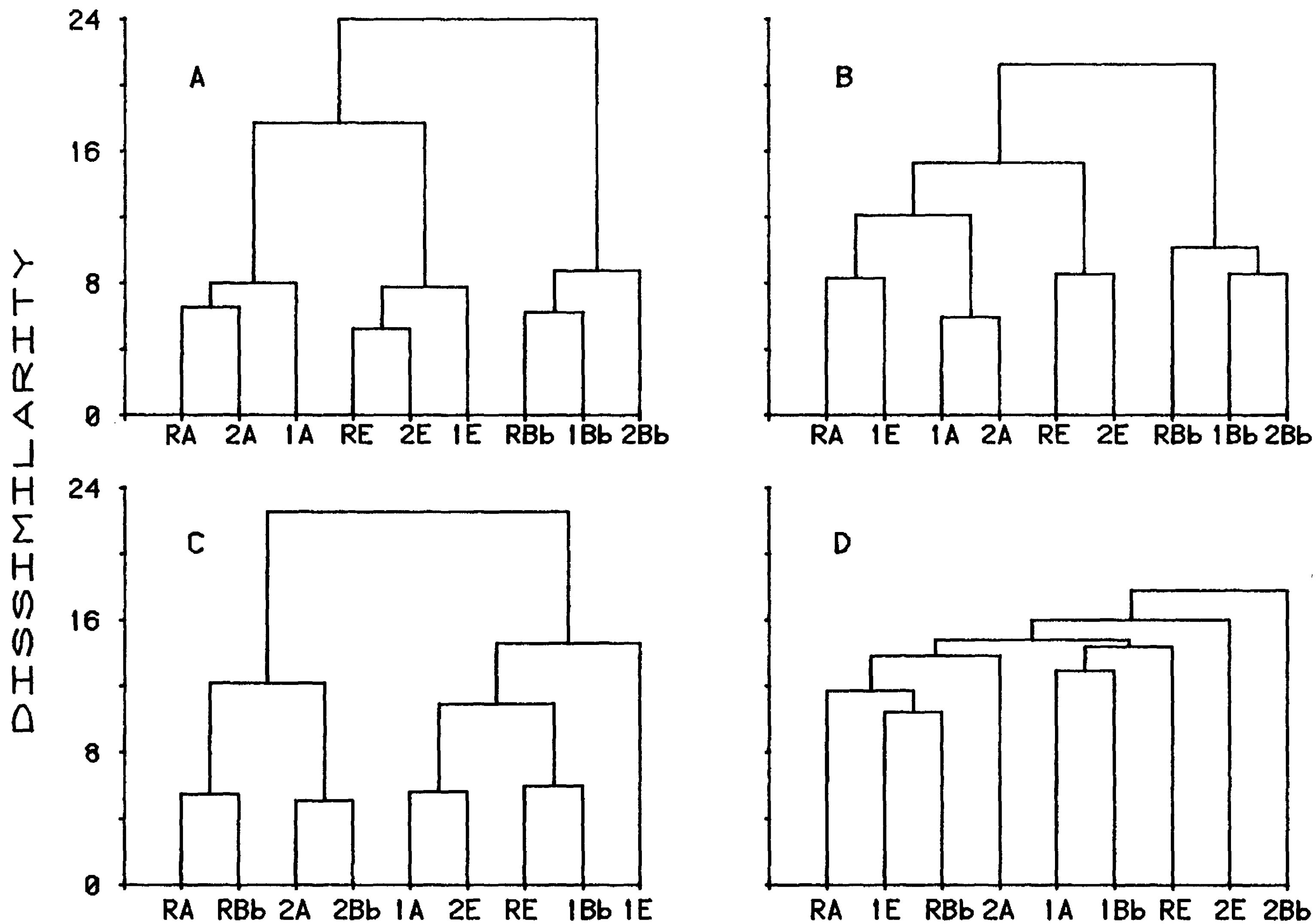
A: Dendrogram for one professional who clustered by root-note.

B: Dendrogram for one moderately-experienced subject who clustered the highly-related A- and E-major chords as a separate group from the distantly related Bb-major chords.

C: Dendrogram for one inexperienced subject who clustered by pitch-height.

D: Dendrogram for one moderately-experienced subject whose results were unclassifiable.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; RBb = Root Bb; 1Bb = First Inversion Bb; 2Bb = Second Inversion Bb)


DISSIMILARITY
24
16
8
0
A
RA 2A 1A RE 2E 1E RBb 1Bb 2Bb
B
RA 1E 1A 2A RE 2E RBb 1Bb 2Bb
C
RA RBb 2A 2Bb 1A 2E RE 1Bb 1E
D
RA 1E RBb 2A 1A 1Bb RE 2E 2Bb

150

hearing deficit separated all three major keys from one another, with a particularly clear separation between the A- and E-major chords in relation to the Bb-major chords.

There was no indication of subjects judging the chords on the basis of pitch-height similarity of the fundamental roots. Such a judgement scheme would most likely have resulted in a merging of the A- and Bb-major chords (fundamental roots = 110 Hz and 116 Hz, respectively), followed by a joining of the E-major chords (fundamental root = 165 Hz).

Multidimensional Scaling

The main analysis of this experiment used the INDSCAL model of the multidimensional scaling program ALSCAL (Young, Takane, & Lewyckyj, 1978). The data matrix for each subject was organized in a similar manner to those used for the cluster analysis, in an N x P format, with N referring to the stimulus chords when they served as standard chords, and P referring to the stimulus chords when they served as comparison chords. The matrices differed from the clustering matrices in that binary data comprised the entries, rather than the total number of times a comparison chord was chosen as sounding similar to a standard chord. A 0 was entered if the comparison chord of the first pair of chords was chosen, and a 1 was entered if the comparison chord of the second pair was chosen. To the extent that standard chords revealed a similar pattern of choices for the comparison chords, the standards would be assumed to have been perceived in a similar manner. Before the scaling analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Simple Matching measure of binary association. The multidimensional scaling procedure described in Chapter II was then performed on each of these matrices. In Figures 23, 24, and 25 are depicted the solution obtained for 4 dimensions, which accounted for 82% of the variance (S-STRESS = .174; STRESS = .112). In Figure 23 can be seen the dimensions of root-note and pitch-height, which were originally detected in the cluster analysis. The horizontal axis displays the pitch-height dimension, in which the stimulus chords are ordered from high to low pitch-height. On the vertical axis the root-note dimension is depicted by a separation of the closely related A- and E-major chords from the more distant Bb-major chords.

The third and fourth dimensions were interpreted as subordinate strategies to the pitch-height and root-note strategies, respectively. The interpretation of these two dimensions as subordinate was advanced by evidence that subjects who used each of the subordinate strategies also tended to be those who utilized the associated dominant strategy, as indicated by individual subject weights. Also, the average subject weights, which indicate the relative importance of each dimension in the similarity judgments, were comparatively low for the two subordinate dimensions in contrast to the dominant dimensions. Figure 24 shows the subordinate pitch-height strategy, labelled pitch typicality, plotted against the dimension of pitch-height. The pitch-typicality dimension is related to the pitch-height dimension to the extent that subjects chose pairs of chords as sounding similar to one another if their pitch-height deviations from the most central chord of the full stimulus set were similar. The ordering of the chordal stimuli is represented by the stimuli at the high and low extremes of the pitch-height continuum (1E, then 2Bb and 2A),

Figure 23. Two dimensions of the 4-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 2.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; RBb = Root Bb; 1Bb = First Inversion Bb; 2Bb = Second Inversion Bb)

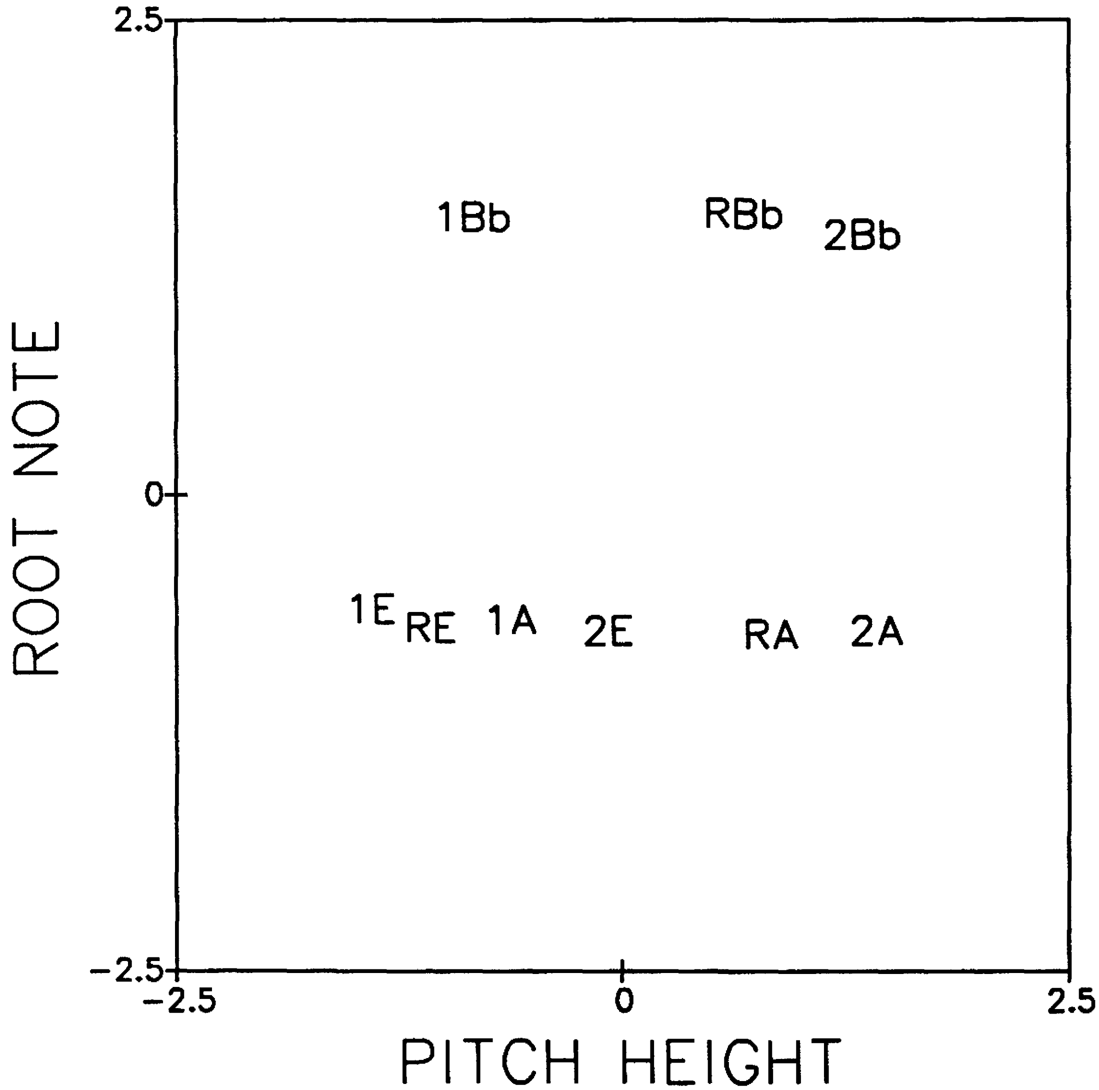

ROOT NOTE
PITCH HEIGHT
2.5
0
-2.5
-2.5
0
2.5
1Bb
RBb
2Bb
1E
RE
1A
2E
RA
2A

Figure 24. Two dimensions of the 4-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 2.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; RBb = Root B; 1Bb = First Inversion B; 2Bb = Second Inversion Bb)

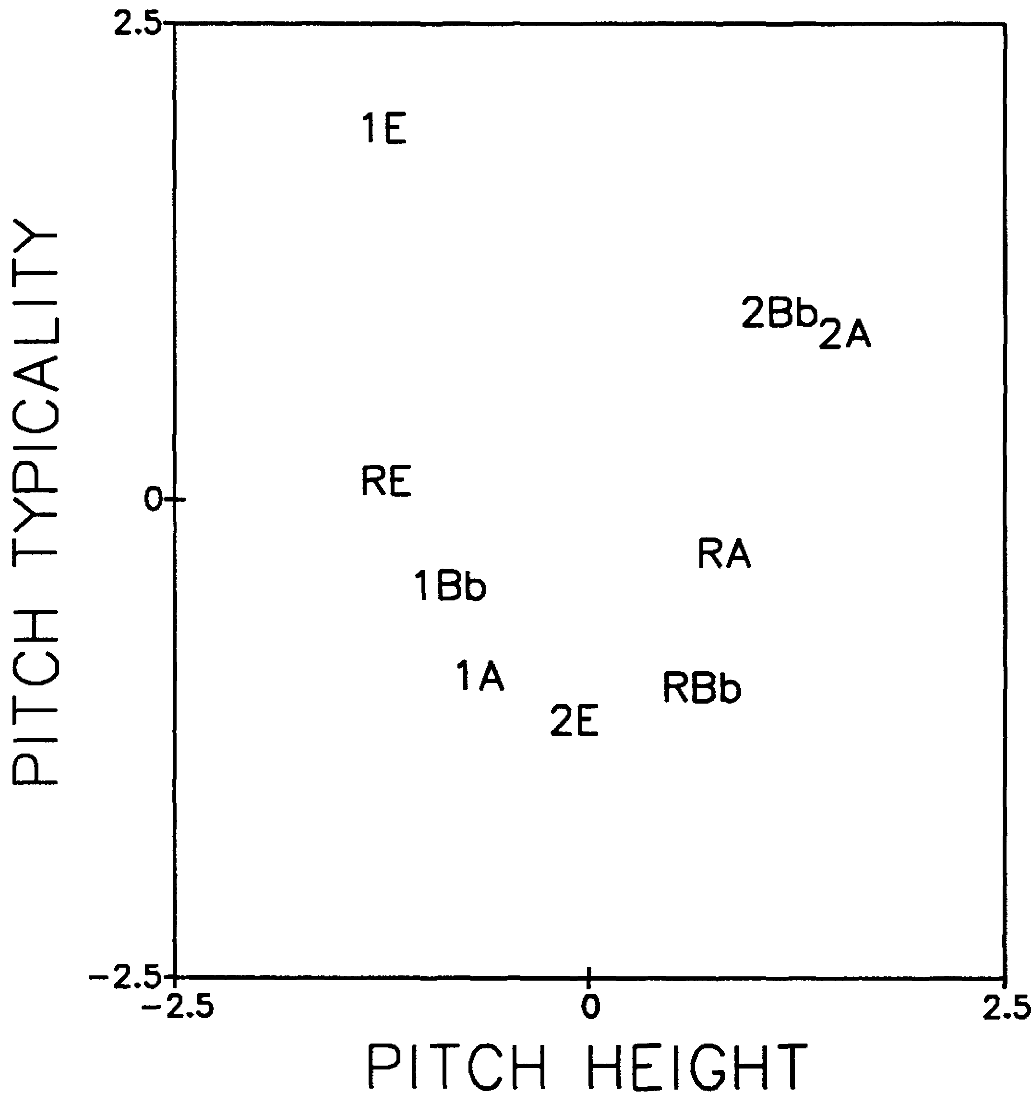
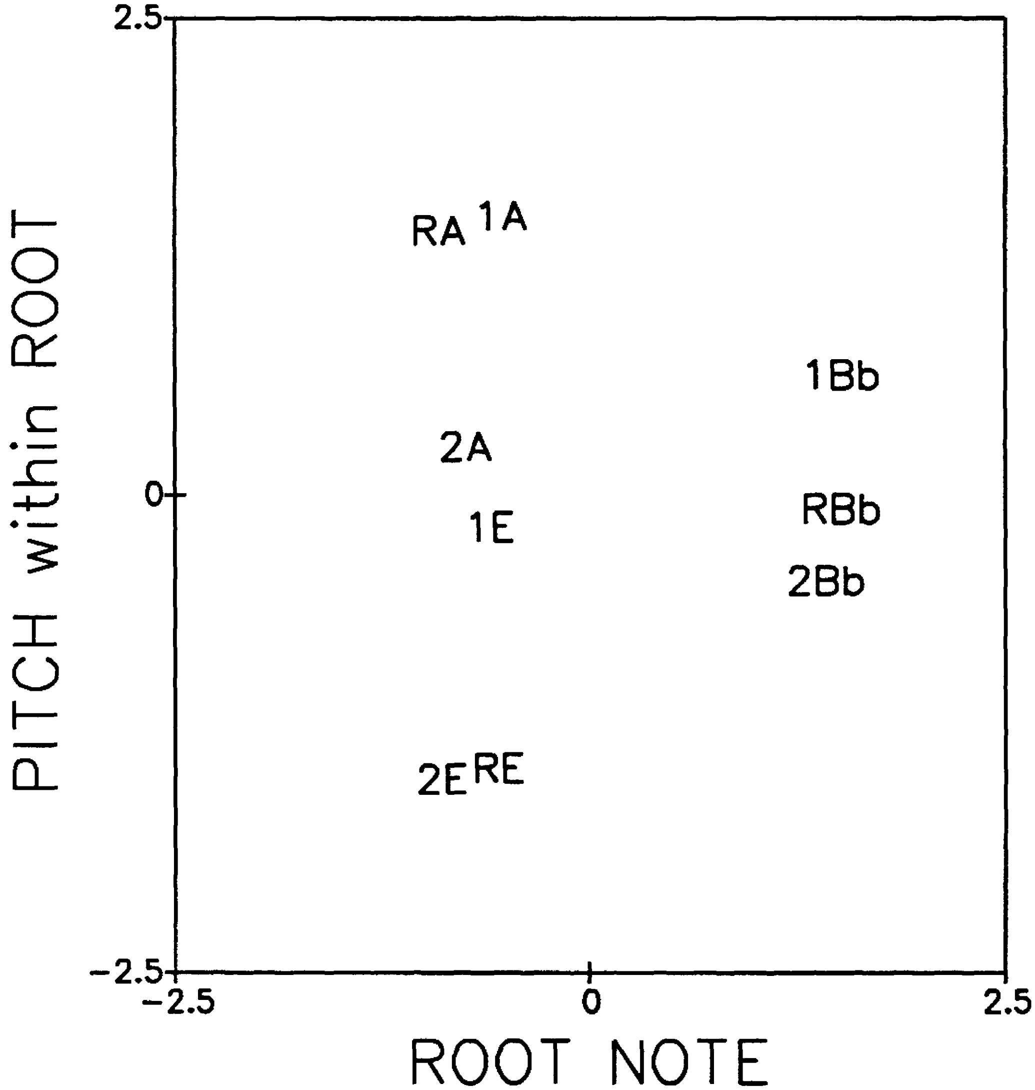

2.5
0
-2.5
-2.5
0
2.5
PITCH TYPICALITY
PITCH HEIGHT
1E
2Bb
2A
RE
RA
1Bb
1A
RBb
2E

Figure 25. Two dimensions of the 4-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 2.

(RA = Root A; 1A = First Inversion A; 2A = Second Inversion A; RE = Root E; 1E = First Inversion E; 2E = Second Inversion E; RBb = Root B; 1Bb = First Inversion B; 2Bb = Second Inversion Bb)



PITCH within ROOT
2.5
0
-2.5
RA 1A
1Bb
2A
RBb
1E
2Bb
2E RE
-2.5
0
2.5
ROOT NOTE

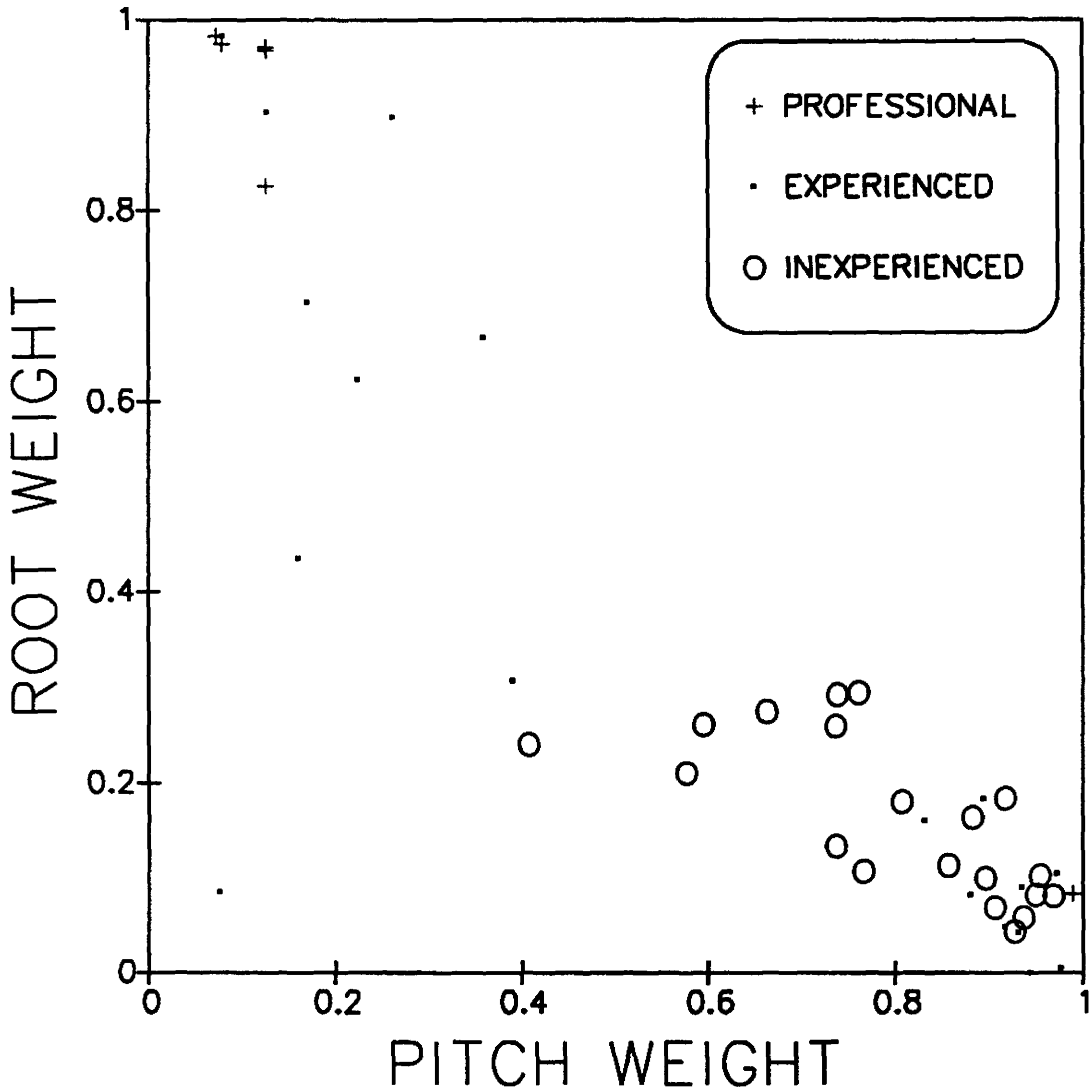
followed by the next least extreme in terms of pitch-height (in the order RE, RA, 1Bb, 1A, then RBb), and finally the chord which fell in the middle of the pitch-height continuum (2E).

Figure 25 displays the subordinate root-note strategy, termed pitch-within-root, plotted against the dimension of root-note. This fourth dimension shows an ordering of the chords on the basis of pitch-height within each of the three sets of triads with the same root-notes. Within each root-note grouping, the chords appear in the order of the highest-pitched chords (first inversion chords) followed by the intermediate-pitched chords (root chords) and then the low-pitched chords (second inversion chords)[6].

Figure 26 presents the derived subject weights for the dominant dimensions of root-note and pitch-height. These weights indicate how strongly a particular dimension predicted a subject's similarity judgements. As can be seen by the strong negative relationship between the weights for these two dimensions, subjects were inclined to use either a root-note or pitch-height strategy, and did not tend to utilize both concurrently. Furthermore, Figure 26 shows that it was the more musically experienced subjects who tended to use a root-note judgement scheme, while the inexperienced subjects relied more on assessments of pitch-height.

Two other graphs plotting subject weights for each of the subordinate dimensions against those for its corresponding dominant dimension are shown in Figures 27 and 28. Both indicate a positive relationship between each dominant strategy and its associated subordinate, showing that subjects who utilized a particular dominant strategy (root-note or pitch-height) also

Figure 26. Derived subject weights for two dimensions of the 4-dimensional INDCAL solution of Experiment 2.



ROOT WEIGHT
PITCH WEIGHT
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
+ PROFESSIONAL
· EXPERIENCED
O INEXPERIENCED

Figure 27. Derived subject weights for two dimensions of the 4-dimensional INDCAL solution of Experiment 2.

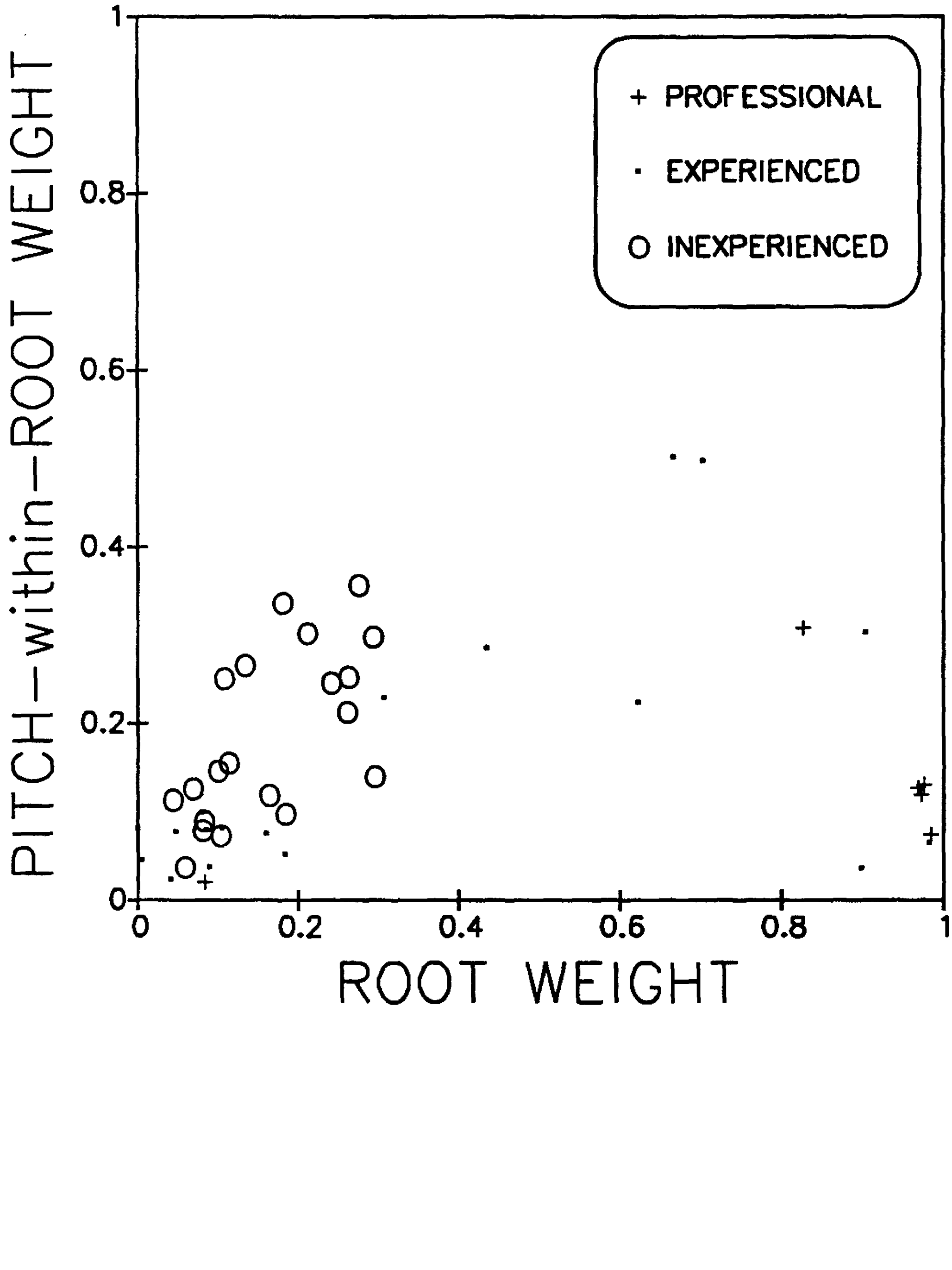
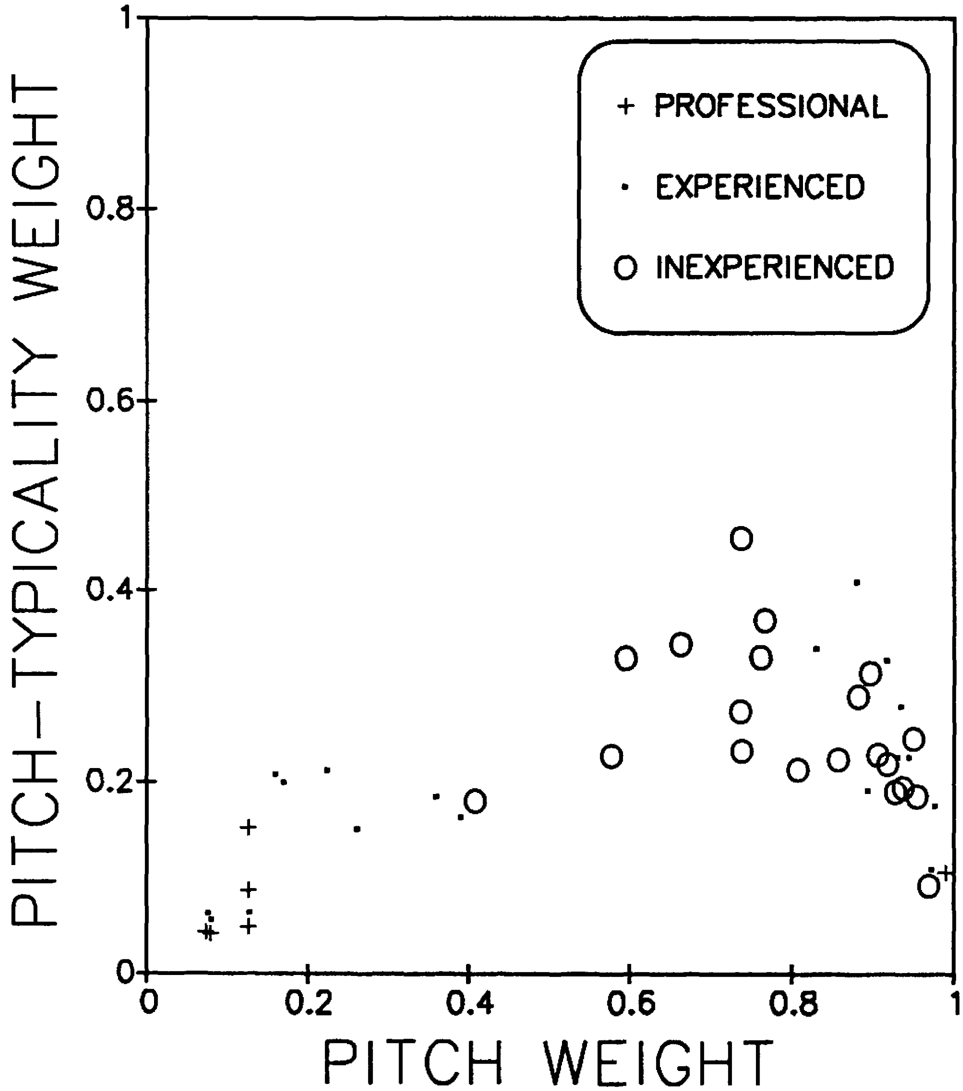

PROFESSIONAL
EXPERIENCED
INEXPERIENCED
PITCH—within—ROOT WEIGHT
ROOT WEIGHT
0
0.2
0.4
0.6
0.8
1

Figure 28. Derived subject weights for two dimensions of the 4-dimensional INDCAL solution of Experiment 2.



1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
PITCH–TYPICALITY WEIGHT
PITCH WEIGHT
+ PROFESSIONAL
· EXPERIENCED
O INEXPERIENCED

tended to be those who at times reverted to an alternate subordinate strategy. Some exceptions to this pattern are noted, however. In Figure 27, in which the pitch-within-root dimension is graphed against the root-note dimension, it can be seen that several professional and moderately-experienced subjects weighted quite highly on the root-note dimension, but apparently did not make use of the pitch-within-root strategy. Likewise, in Figure 28, one can see that there are a number of inexperienced and moderately-trained musicians along with one professional musician who weighted highly on the pitch-height dimension but not on that of pitch-typicality.

Discussion

The similarity judgements of Experiment 2 indicate that inclusion of a maximally-distant key, Bb major, in the context of an experiment in which two maximally-related keys, A and E major, were also presented, resulted in a higher proportion of moderately-experienced subjects using a root-note judgement strategy (7 of 18 moderately-experienced subjects), relative to Experiment 1 in which only two maximally-related keys were presented (2 of 20 moderately-experienced subjects). Almost all of the professionals in Experiments 1 and 2 utilized a root-note strategy, and almost all of the inexperienced subjects in Experiment 1 and all of the inexperienced subjects in Experiment 2 made ratings on the basis of pitch-height. It appears then, that support has been obtained for major triads functioning as instantiators of key in their own right. More specifically, in the absence of elaborate musical cues (e.g., melodies, scales, cadences), the more musically-trained subjects were able to interpret isolated triads in terms of the musical keys from which they were drawn. It necessarily follows that the more highly-trained subjects who judged the triads on the basis of root-note, also perceived the three inversions built on the same root-note as sounding similar to one another.

It is proposed that the reason a greater number of moderately-experienced subjects in Experiment 1 did not exhibit a separation of the chords by root-note was due to the presentation of only two maximally-related keys. The multiple harmonic functions shared between these two keys may have made it possible for only the most highly-trained individuals to separate the chords on the basis of root-note, perhaps due to a more firmly established and more frequently accessed chordal hierarchy. When, however, triads from a more distant key were presented, the relevant cues to trigger triad judgements on the basis of root-note may have been provided, although the moderately-trained subjects still exhibited some confusion about separating the A- and E-major chords from one another. Also, given that the same ambiguous instruction was given in both Experiments 1 and 2 (to judge "similarity" of the chords, with no further clarification as to what dimension of the chordal stimuli should be judged), it would appear that the presence of the Bb-major chords encouraged more root-note judgements.

Several anomalous patterns of results were encountered with respect to the general pattern of clustering solutions obtained for the musically-experienced subjects. One such result was obtained with a professional subject, who separated the A- and E-major chords as a group from the Bb-major chords, but did not separate the A- and E-major chords from each other. Further inquiry into this particular subject's musical training, however, revealed that this subject had received his training on a non-Western instrument (the tambura), and had been exposed to a great deal of non-Western music. Experience with a different tonal system could account for the confusion between the highly related A- and E-major triads, as the majority of other professionals were able to separate these two keys from one another (see Castellano, Bharucha, & Krumhansl, 1984).

Another unexpected result, also exhibited by a professional musician, was a pitch-height pattern of judgements typically observed among the untrained subjects. This subject had asked the experimenter after the first block of trials whether the desired judgement dimension was pitch-height or some other stimulus attribute, indicating that he was aware of the presence of more than one dimension on which the chords could be judged. It is questionable, however, whether or not judgements concerning the triads can be made at will, as instructions to judge root-note in Experiment 1 were not sufficient for a highly-trained subject to shift from an uninterpretable result to one where root-note was judged.

Three chords, 1A, 2E, and RBb, had been selected in this experiment because of their locations on the staff, such that they might serve as a flag for subjects using a pitch-height judgement scheme. These chords differed in both position and root-note, but were of very similar pitch-heights. If a subject grouped these chords together, therefore, it would be assumed that they were judged on the dimension of pitch-height. However, no subject utilizing a pitch-height strategy exhibited a direct clustering of these three chords, and instead, most pitch-height subjects tended to group the four lowest pitched chords (which included RBb) of the stimulus set as one cluster, and the five highest chords (which included 2E and 1A) as another cluster. Although subjects did not follow the predicted pitch-height judgement scheme in terms of these three chords, the observed pitch-height patterns were so clear that further speculation did not seem warranted.

Conclusion

It is proposed on the basis of this experiment, that the major triad in isolation can induce a sense of musical key, but this is limited to individuals who have established a representation of chordal functions through formal experience with a particular tonality system. By including a greater range of chords, in terms of their degrees of relatedness, more of the moderately-experienced subjects were observed to utilize a root-note strategy, indicating that they possessed an underlying representation of chord functions, and that they could access this representation without provision of more extensive musical context than major triads. Professional musicians were able to make a discrimination even between maximally-related keys, indicating a quite highly organized system of chord relations. Furthermore, the grouping of different chord positions together in the same key supported the notion of inversion equivalence, at least with respect to tonality. Musically- inexperienced individuals appeared able to make judgements at only the level of pitch-height.

To provide a more complete description of the key distance effect, Experiment 3 was conducted in a similar manner to Experiment 2, but included a greater number of keys spanning the Circle of Fifths. It is was hoped that inclusion of more chordal stimuli would provide even more contextual cues to key, and result in an even greater proportion of moderately-experienced subjects resorting to root-note judgements.

CHAPTER V

EXPERIMENT 3

In Experiment 2, a higher proportion of moderately-experienced subjects, relative to those in Experiment 1, demonstrated that isolated musical triads are capable of providing tonality cues, as reflected by a separation of these chords according to their degrees of relatedness. In Experiment 1 only tonic triads from two maximally-related keys, A and E major, were presented; but in Experiment 2 tonic triads from a maximally-distant key, Bb major, were also presented. It was perhaps the presence of the Bb-major triads within the context of Experiment 2 which contributed to a greater proportion of subjects utilizing a root-note judgement scheme, although the majority of moderately-trained individuals in Experiment 2 still did not separate the A- and E-major chords from one another. Only when highly-trained professionals were tested was a separation of the highly related A- and E-major chords observed (Experiments 1 and 2), with a particularly strong separation demonstrated between the A- and E-major chord cluster and the maximally-distant Bb-major chords (Experiment 2).

To provide a more complete description of the key distance effect, Experiment 3 was conducted in a manner similar to Experiment 2, but included a greater number of keys spanning the Circle of Fifths. It would seem a next logical step to test the perceived similarities of triads encompassing two maximally-dissimilar keys along with all the keys contained between them. By continuing to present the two maximally-unrelated keys of E major and Bb major, as were used in Experiment 2, the key span would include the major keys of E, A, D, G, C, F, and Bb major. Also, because the keys of A and E major are included within this span, and they had previously been used in Experiments 1 and 2, a useful comparison with these previous studies would be provided. If responses fell in the order predicted by the Circle of Fifths, then empirical support for this theoretical underlying structure of musical triads would be obtained. Importantly, this structure would be recovered in the absence of a musical context consisting of more than major triads! This finding would lend further credence to claims that major triads can act to instantiate key in their own right.

It was also necessary in Experiment 3 to include all inversions of the major triads in order to continue investigating the claimed equivalence between harmonic inversions. If these inversions are separated into the keys from which they are drawn, as they were in Experiments 1 and 2, then stronger evidence will have been gathered for roots, first inversions, and second inversions as effective conveyers of key.

Using a greater number of keys would make testing under the same two alternative-forced choice paradigm used in Experiments 1 and 2 unmanageable. Instead, an arbitrarily selected key, E major, served as the key from which the standard chord was selected throughout the entire study. All other chords and their inversions were then compared to this one standard. In this way, the context was established as that of E major, and if the hypothesized chordal hierarchies exist, one should be able to obtain ratings which recover the

Circle of Fifths with respect to this standard key. That is, chords more highly related to E major should be judged as more similar to this key, while those more distant should be judged as less similar. In order of decreasing similarity from the key of E major, the keys should appear as: E, A, D, G, C, F, Bb.

The 21 chords which result from presenting 7 chords in each of three positions could also be judged on the basis of pitch-height. In order of increasing pitch-height, these chords are ranked as follows: 2F, 2G, RF, 2A, 2Bb, RG, 2C, RA, 1F, RBb, 2D, 1G, RC, 2E, 1A, RD, 1Bb, RE, 1C, 1D, 1E, where R = Root, 1 = First Inversion, 2 = Second Inversion, and all other letter symbols refer to root-note. Originally, selection of the standard chord was intended to be RE, because of the choice of E major to be the key from which the standard would be chosen, and because of the stability of the root chord position. However, given that the 1E chord appears at one extreme of the pitch-height continuum, and because of the supposed equivalence of root and first inversion chords, the 1E chord served as the standard triad for Experiment 3. Although the use of a standard at one end of the pitch-height continuum might increase the salience of pitch-height, such a stimulus set would provide a more stringent test for subjects using a root-note strategy. That is, any subject using a root-note strategy would have to ignore potentially strong cues to pitch-height.

Given the stable finding in Experiments 1 and 2 that inexperienced subjects relied on pitch-height judgements, they were not expected to switch to root-note judgements in an experiment containing a greater number of triads to be judged. For this reason, only moderately-trained and professional musicians were recruited for Experiment 3. If these subjects displayed a strong root-note effect, then musically inexperienced subjects would also be recruited.

Method

Subjects. Twenty-three individuals were recruited to serve as subjects. Twelve of these subjects were musicians in the Hamilton, Ontario community; 9 were enlisted from an undergraduate introductory psychology course; 1 was a student in a music perception laboratory course; and 1 was the experimenter herself. The subjects were grouped according to 2 experience levels, professional musicians and moderately-trained musicians, in accordance with the criteria specified in the earlier experiments, except that undergraduate music majors were now classified as part of the moderately-trained group in an effort to make the criterion for professional status more stringent. The professional group was comprised of 11 individuals, each of whom was paid $5 for participation. The training of these 11 subjects ranged from 7.5 to 24.0 years on their self-designated primary instruments (mean = 14.3 years). They reported theory training ranging from 1 year of study to university-level theory courses (8 subjects held one or more university degrees in music). All subjects played more than one instrument. Current musical involvement in the form of playing one's primary instrument, teaching, and studying music was reported at an average of 32.0 hours per week, while mean listening activity was reported at 2.9 hours per day. Nine of the 11 professionals reported family members who at some time played a musical instrument. One of these subjects reported having absolute pitch. Of these 11 professional musicians, 5 were male and 6, female.

The training of the 12 subjects considered moderately trained ranged from 5.0 to 16.0 years on their self-designated primary instruments (mean = 9.8 years). All subjects reported theory training (mean level attained = 3.5 years), and 10 of the subjects played more than one instrument. All of the subjects also reported participation in other musical activities such as band and choir at some time during their music studies. Current musical involvement in the form of playing one's primary instrument was reported at an average of 12.6 hours per week, while mean listening activity was reported at 3.4 hours per day. All of the 11 moderately-trained subjects reported family members who were at some time involved with music. None reported absolute pitch. Of the 12 moderately-trained subjects, 2 were male and 10, female.

One of the professionals reported tinnitus in both ears, and one moderately-trained subject reported a slight hearing loss in her left ear. All other subjects claimed normal hearing.

Apparatus. All apparatus was the same as Experiments 1 and 2.

Stimuli. Each trial consisted of the presentation of two pairs of chords. All tones comprising the chords were sine waves and were of equal temperament.

Chords presented in this experiment included the identical A-major, E-major, and Bb-major chords in root, first inversion, and second inversion positions used in Experiment 2. (The E-major first-inversion triad, 1E, was designated as the standard chord for all trials.) In addition, analogous positions were constructed on the tonics for the four other triads representing different keys. These included the F-major chords in root form (F: 349.2 Hz, A: 440 Hz, C: 523.3 Hz), first inversion (A: 440 Hz, C: 523.3 Hz, F: 698.5 Hz), and second inversion (C: 261.6 Hz, F: 349.2 Hz, A: 440 Hz); G-major chords in root form (G: 392 Hz, B: 493.9 Hz, D: 587.3 Hz), first inversion (B: 493.9 Hz, D: 587.3 Hz, G: 784 Hz), and second inversion (D: 293.7 Hz, G: 392 Hz, B: 493.9 Hz); C-major chords in root form (C: 523.3 Hz, E: 659.3 Hz, G: 784 Hz), first inversion (E: 659.3 Hz, G: 784 Hz, C: 1046.5 Hz), and second inversion (G: 392 Hz, C: 523.3 Hz, E: 659.3 Hz); D-major chords in root form (D: 587.3 Hz, F#: 740 Hz, A: 880 Hz), first inversion (F#: 740 Hz, A: 880 Hz, D: 1174.7 Hz), and second inversion (A: 440 Hz, D: 587.3 Hz, F#: 740 Hz). Figures 29A and 29B contain the musical notation of these stimuli in order of increasing pitch-height across the stimulus set, and in order of increasing key distance from the standard stimulus chord, 1E, on the Circle of Fifths.

The sampling rate for all nine stimulus chords was 20,000 Hz. To prevent aliasing, a low-pass filter cutoff was set at 10,000 Hz. Rise and fall times were set at 50-msec. Measurement with an arificial ear and SPL meter indicated all stimulus chord presentations to be at 72±1 dB SPL.

The fundamental roots for each of the stimulus chords were as follows: 165 Hz for the E-major chords; 110 Hz for the A-major chords; 147 Hz for the D-major chords; 98 Hz for the G-major chords; 131 Hz for the C-major chords; 87 Hz for the F-major chords; 116 Hz for the Bb-major chords. These figures are included in order to identify subjects who might attend to the pitch-heights of the fundamental roots of these chords.

All duration parameters for the presentation of chords were the same as for Experiments 1 and 2. Furthermore, the configurations and instructions presented on the monitor were identical to the earlier studies.

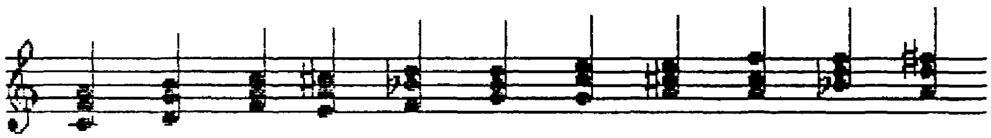
Figure 29. Musical notation of stimuli used in Experiment 3.

A: Triads presented in order of increasing pitch-height.

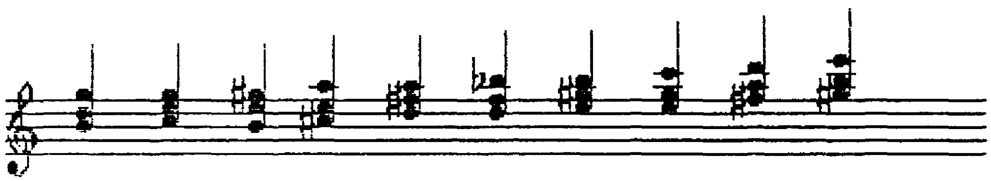
B: Triads grouped by common root-note.

(R = Root; 1 = First Inversion; 2 = Second Inversion; All other characters = Root Note)

A

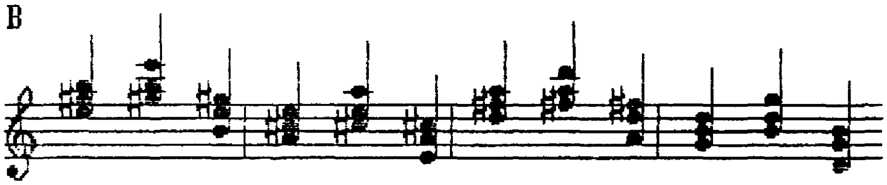


2F 2G RF 2A 2Bb RG 2C RA 1F RBb 2D

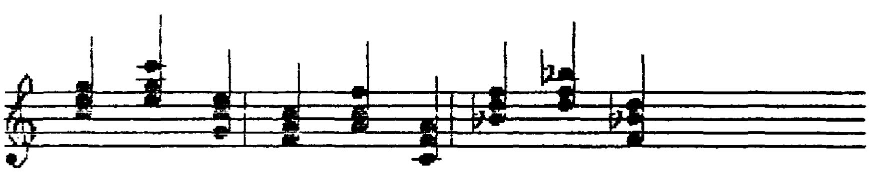


1G RC 2E 1A RD 1Bb RE 1C 1D 1E

B



RE 1E 2E RA 1A 2A RD 1D 2D RG 1G 2G



RC 1C 2C RF 1F 2F RBb 1Bb 2Bb

There were three trial blocks. Subjects received a 5-min break from the experiment between each block.

Procedure. A paired-comparison paradigm was employed for presentation of the 21 chordal stimuli with the constant standard. A condition of the chord presentations demanded that the second chords of each pair on a trial could be any one of the 21 stimuli as long as the two were not identical on a trial. After each of the 21 chords was presented in every possible order and combination with the constant standard, in compliance with the conditions stated above, a total of 420 trials (140 trials per trial block) resulted. Subjects were instructed that the first chord of each pair would be the same throughout the entire experiment. All other procedural details were identical to Experiments 1 and 2.

Results

Correlation Analysis

A preliminary correlation analysis was conducted in an attempt to determine if subjects were using either a root-note or a pitch-height strategy. Two Spearman rank correlation coefficients were computed for each subject: a correlation of the subject's ranked choice scores and the predicted ranks of choice scores for a strict key ordering according to the Circle of Fifths, and a correlation of the subject's ranked choice scores and the predicted ranks of choice scores for a strict pitch-height ordering. The subject's ranked choice scores were computed by ranking the subject's comparison chord choices from 1 to 21, with 1 assigned to the chord chosen most often as sounding similar to the standard, and 21 assigned to the least-chosen chord. Because triads possess the attributes of both pitch-height and key, a confound existed between the pitch-height and Circle of Fifths ordering of the stimulus chords (r_s = .40). This correlation of .40 should be regarded as the extent to which the two strategies were correlated, indicating that even if subjects were to exhibit perfect correlations with one of the two strategies, there would also be some influence of the alternative strategy. Table 1 presents the results of these correlation analyses in descending order from the subject displaying the highest correlation with the Circle of Fifths (r_s = .89) to the subject with the lowest correlation (r_s = -.05). In general, as the rank order correlation for subjects' ranked choice scores and Circle of Fifths rank decreased, the correlations for pitch-height increased. There were exceptions, however, in that several subjects displayed high positive correlations that were nearly equivalent for pitch-height and the Circle of Fifths, and several showed such low correlations with both strategies that it would be difficult to determine which, if any, of these two strategies they might have been using.

Regarding the professional who reported absolute pitch, his results were uninterpretable as to whether he relied more on pitch-height (r_s = .52) or root-note (r_s = .56), although his correlation results were slightly in the direction of root-note.

The results for one professional and one moderately-experienced subject who reported slight hearing problems were not distinguishable from the other subjects. The correlations of the choice scores of the professional were nearly equivalent with both root-note (r_s = .56) and pitch-height (r_s = .69), with the pitch-height correlation slightly higher. The moderately-experienced subject

Table 1

Experiment 3

SPEARMAN RANK ORDER CORRELATIONS
FOR SUBJECTS' RANKED CHOICE SCORES
AND PITCH-HEIGHT RANKS, AND SUBJECT'S RANKED
CHOICE SCORES AND CIRCLE OF FIFTHS RANKS

(SUBJECTS SORTED ON BASIS OF DECREASING
CIRCLE OF FIFTHS CORRELATIONS)

SUBJECT (E = MODERATELY EXPERIENCED; P = PROFESSIONAL)	PITCH-HEIGHT	CIRCLE OF FIFTHS
E	.48	.89
P	.50	.85
E	.18	.80
P	.70	.78
P	.39	.76
P	.75	.76
P	.84	.69
E	-.03	.67
E	.79	.62
E	.42	.57
P	.52	.56
P	.69	.56
E	.92	.54
P	.42	.52
P	.25	.46
P	.89	.46
E	.99	.42
E	.95	.40
E	.96	.39
E	.99	.22
E	.19	.19
E	.92	.01
P	.92	-.05

clearly showed a reliance on pitch-height (root-note r_s = .22; pitch-height r_s = .99).

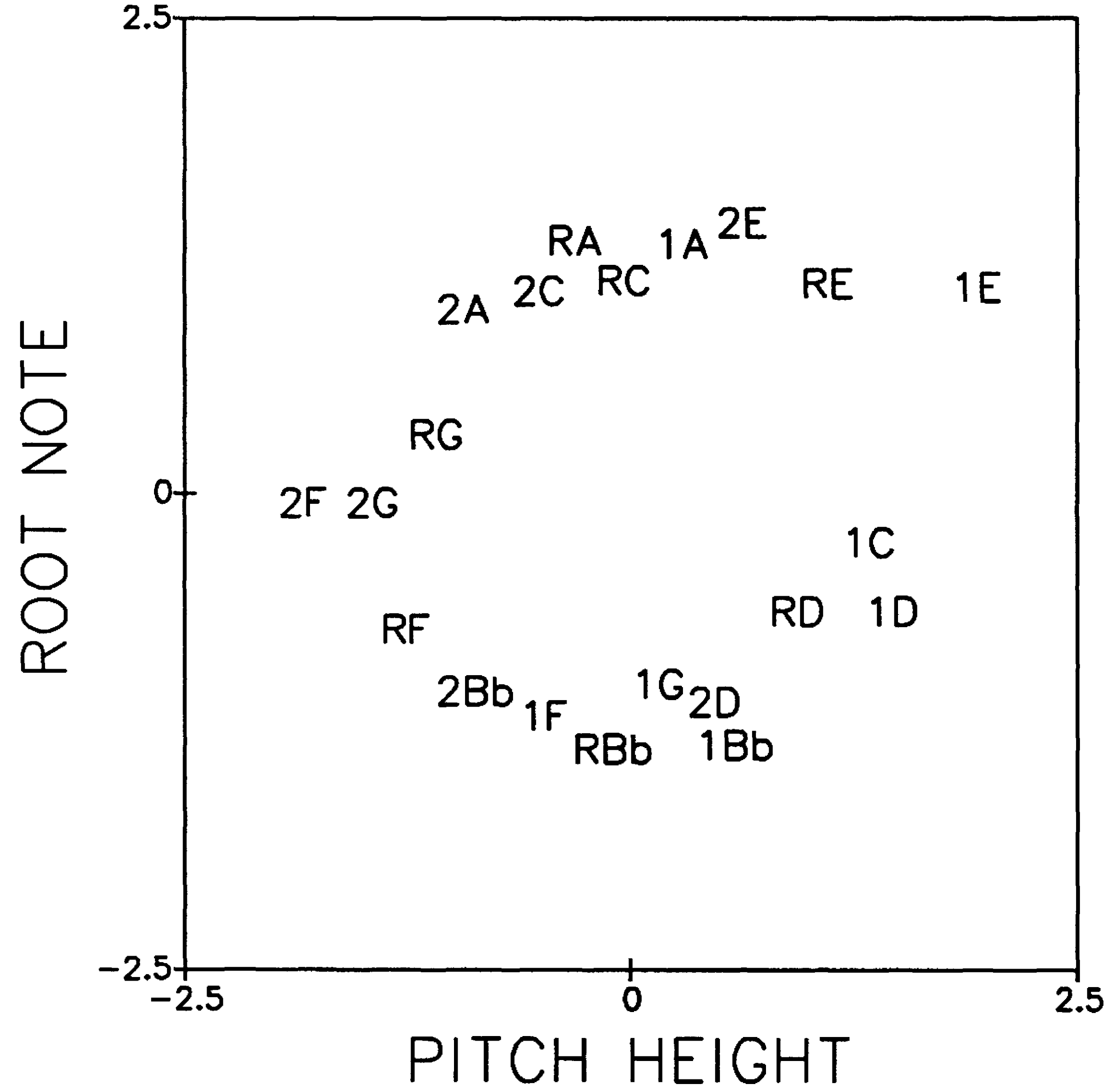
Multidimensional Scaling

The main analysis of this experiment used the INDSCAL model of the multidimensional scaling program ALSCAL (Young, Takane, & Lewyckyj, 1978). The data matrices for each subject were arranged in an N x P format, in which N refers to the stimulus chord which served as the comparison in the first pair of chords, and P refers to the stimulus chord which served as the comparison in the second pair of chords. The entries within the matrices consisted of binary data, with 0 indicating a choice of the first comparison chord, and 1 indicating a choice of the second comparison chord. To the extent that a subject's pattern of choices for compariosn chords presented in second pairs was similar for comparison chords presented in first pairs, those chords presented in first pairs would be assumed to have been perceived in a similar manner. In this way, it was actually the first-pair chords which were scaled in the scaling analysis. Before the scaling analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Simple Matching measure of binary association. The multidimensional scaling procedure described in Chapter II was then performed on each of these matrices. The two-dimensional solution, which accounted for 28% of the variance (S-STRESS = .477, STRESS = .352), was chosen for presentation, despite the presence of a clear elbow at four dimensions when a STRESS by Dimensions graph was plotted. Although the four dimensional solution accounted for a marginally higher percent of the variance, 29%, with slightly lower S-STRESS and STRESS values (S-STRESS = .353, STRESS = .219), a multidimensional scaling solution is only useful to the extent that its dimensions are interpretable. The four-dimensional solution contained two dimensions which could not be interpreted by the experimenter to be related to either a musical or psychophysical judgement of the triads, whereas the two-dimensional solution offered dimensions to which a plausible interpretation could be put forth.

The two-dimensional solution, which did not give a very good fit to the data, as indicated by a low RSQ value and high S-STRESS and STRESS values, is shown in Figure 30. The figure reflects the root-note and pitch-height dimensions for which the preliminary correlation analysis tested. Along the horizontal axis is displayed the pitch-height dimension, in which the stimulus chords were ordered from low to high pitch-height, with occasional juxtapositions between a chord lower in pitch with one that was higher in pitch. On the vertical axis is depicted the dimension of root-note. This dimension can be most easily read by proceeding from the E- and A-major chords, which were most highly related to the 1E standard, to the Bb-major chords, which were the most unrelated chords to the 1E standard. The root-note dimension, if read in this way, shows the E- and A-major chords followed by two rather scattered groupings of C- and G-major chords, and finally a somewhat mixed grouping of F-, D-, and Bb-major chords. A strict Circle of Fifths ordering would require the ordering of major chords in terms of decreasing relatedness to the 1E standard to be: E, A, D, G, C, F, Bb major. As can be seen in the resultant scaling analysis, however, the D- and C-major chords were reversed with respect

Figure 30. Two-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 3.

(R = Root; 1= First Inversion; 2 = Second Inversion; All other characters = Root Note)


2.5
0
−2.5
−2.5
0
2.5
ROOT NOTE
PITCH HEIGHT
RA
1A
2E
2C
RC
2A
RE
1E
RG
2F
2G
1C
RD
1D
RF
2Bb
1G
2D
1F
RBb
1Bb

to the predicted Circle of Fifths ordering. Furthermore, the clusters of triads sharing the same root-note were not as compact, nor was the organization between the different keys as orderly as one would have predicted on the basis of the theoretical key relationships depicted by the Circle of Fifths.

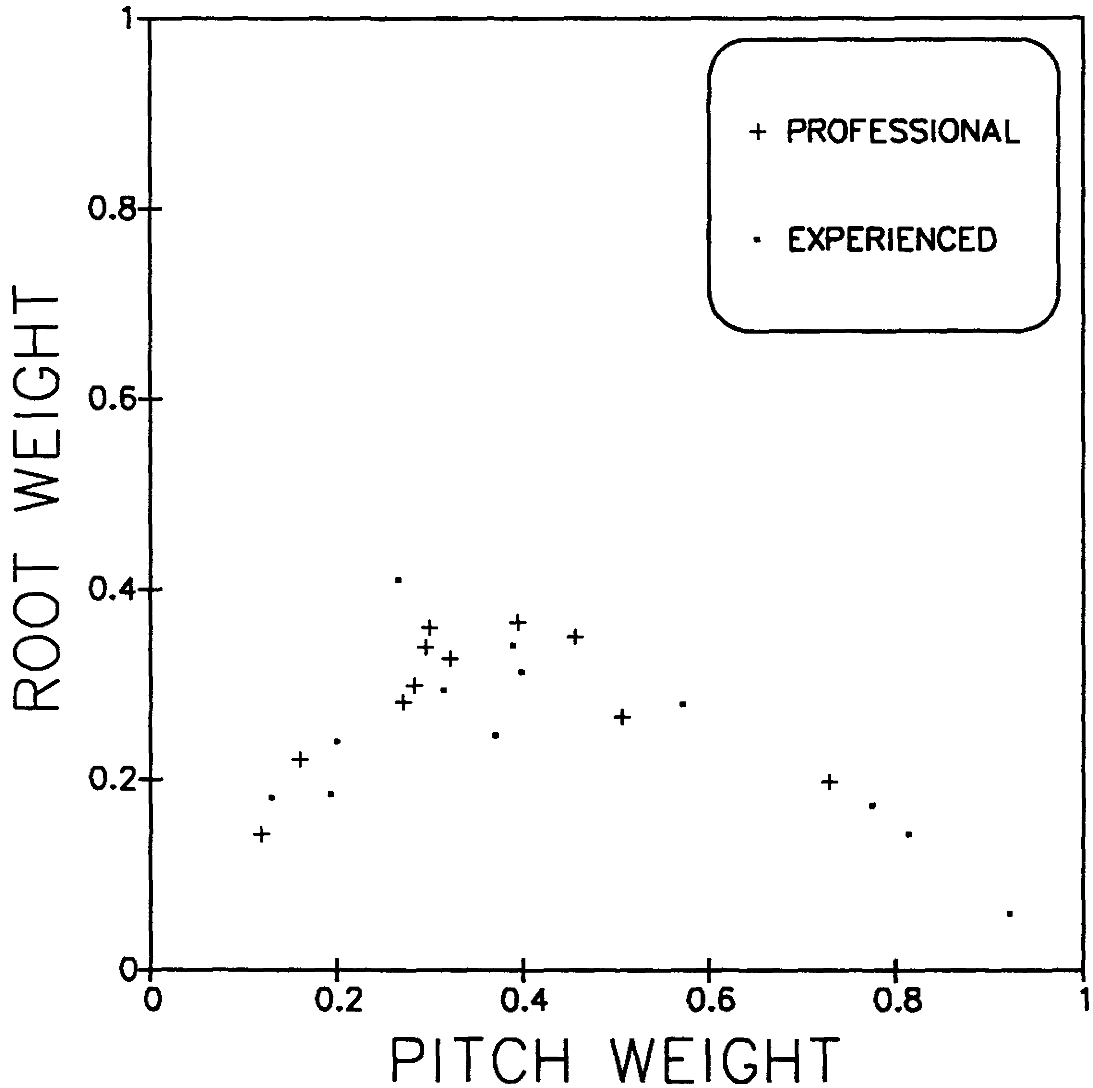
Figure 31 presents the derived subject weights for the root-note and pitch-height dimensions. No subject's weights were particularly high on the root-note dimension relative to the dimension of pitch-height. There was a generally negative relationship between the root-note and pitch-height weights, although a number of subjects appeared to have nearly equivalent weightings on both dimensions, patterns which were first detected in the preliminary correlation analysis. Several subjects displayed fairly high weights for the pitch-height dimension relative to weights for root-note. No apparent distinction could be made between professional and moderately-trained individuals regarding their use of either a root-note or pitch-height strategy.

There was no evidence from the scaling solution that subjects had based their judgements on the relative pitch-heights of the fundamental roots of the triads. If this had been the case, an expected ordering of the triads would have been: F, G, A, Bb, C, D, E, where the fundamental roots were 87 Hz, 98 Hz, 110 Hz, 116 Hz, 131 Hz, 147 Hz, and 165 Hz, respectively.

Discussion

It is evident from the results of this experiment that root-note was not a dominant factor on which these highly-trained subjects based their decisions. The multidimensional scaling solution accounted for only 28% of the variance in the data, indicating that the subjects' data were not fit very well by

Figure 31. Derived subject weights for 2-dimensional INDSCAL solution of Experiment 3.



ROOT WEIGHT
PITCH WEIGHT
+ PROFESSIONAL
· EXPERIENCED
0
0.2
0.4
0.6
0.8
1

the model. Furthermore, no distinction could be made between the professional and moderately-trained musicians with regard to root-note and pitch-height strategies, as indicated by the derived subject weights. Some support for sensitivity to the root-note dimension could be found only in that triads more distantly related on the Circle of Fifths were depicted at further distances from one another in the scaling solution. It was perhaps the multiple harmonic functions shared between closely related triads that prevented a more distant spacing between them. Further substantiation for the inversion equivalence found in the two earlier experiments was found in the present experiment by the loose groupings of triads sharing the same root-note.
A number of factors could have contributed to the less than clear scaling configuration with regard to root-note. One of the most obvious possible influences was the large number of chordal stimuli required to be judged. Twenty-one stimuli were used in the present experiment, as compared to the nine chordal stimuli in Experiment 2, where a clear separation by root-note was observed in subjects with comparable degrees of musical experience. To have expected perfect orderings conforming to the Circle of Fifths for such a large number of triads, with no provision of musical context beyond the triads themselves, may have been overly optimistic.

Contributing to the unclear results could have been the selection of chords which were too closely spaced on the Circle of Fifths. It was shown in Experiments 1 and 2 that it was especially the moderately-trained subjects who had difficulty in separating the maximally-related A- and E-major triads from one another. These subjects were, however, able in Experiment 2 to separate the A- and E-major triads from the maximally-distant Bb-major triads. Perhaps the presentation of chords from 7 adjacent keys on the Circle of Fifths made the task nearly impossible.

Two further potential difficulties in this experiment stemmed from differences in how the Circle of Fifths is used in actual musical practice and how it was employed in the present experiment. In this experiment, a constant standard E-major chord was used, and triads were selected by moving counterclockwise from this standard chord. As stated in Chapter I, modulations between keys tend to occur between keys a musical fifth apart, via a clockwise movement on the circle. It is possible that the subjects were sensitive to this practice and were therefore confused by movement in the opposite direction, a movement in which modulations would be taking place by musical fourths.

The other difficulty regarding the Circle of Fifths concerned the use of a constant standard. Movement around the circle, in terms of the practices of elementary classical harmony, is usually to adjacent keys on the circle, not from a standard key to a number of distant keys. The use of a constant standard that also happened to fall at one end of the pitch-height continuum of stimulus chords could also have been problematic. As shown in Figure 31, no subjects weighted very heavily on the root-note dimension, but a few subjects did show high weights on the dimension of pitch-height. Usage of a standard chord which fell at the high end of the pitch-height range could have encouraged judgements of the chords on this attribute.

Finally, it could be that in Experiment 2 subjects were able to separate the closely-related A- and E-major triads from the more distant Bb-major triads because they were aware of a shared note (E) between the A and E chords, and no shared notes between these chords and those of Bb major. If subjects performed on the basis of this type of strategy for the present experiment, they would not be expected to give a correct ordering according to the Circle of Fifths when making comparisons against a constant standard. Such an explanation would not, however, explain the ability of the majority of professional musicians to distinguish between the two maximally-related keys in Experiments 1 and 2.

Conclusion

The results of Experiment 3, in which 21 chords were judged in relation to a standard chord by professional and moderately-experienced musicians, indicated 2 dimensions on which subjects based their judgements. These included a root-note dimension, in which triads were loosely ordered on the basis of their Circle of Fifths relationships, and a pitch-height dimension. No conclusions could be drawn regarding a relationship between subjects' musical backgrounds and usage of one of these strategies.

Because of the emergence in Experiment 3 of a dimension loosely following root-note relationships on the Circle of Fifths, and the evidence in Experiments 1 and 2 that professional musicians are possibly performing in this manner, the idea that major tonic triads can function as tonal units in the absence of more elaborate musical context, was not abandoned in Experiment 4. In keeping with the belief that highly-experienced individuals have established a hierarchy of chordal functions and relationships, the next experiment followed a more familiar pattern based on movement by fifths rather than fourths. The chordal stimuli were drawn from a clockwise movement on the circle, retaining the 1E chord as the standard to which chords built on 7 different root-notes would be compared. In this way, the practice of modulating by musical fifths was followed.

CHAPTER VI

EXPERIMENT 4

In Experiment 3, when 21 major triads drawn from counterclockwise movement on the Circle of Fifths were presented to highly-skilled musicians, the obtained similarity judgements did not reveal a strong root-note dimension. It was questioned whether the subjects in Experiment 3 may have been affected by the counterclockwise movement around the circle, in which movement would be occurring by musical fourths rather than the more usual movement by musical fifths. Furthermore, when moving counterclockwise seven keys on the Circle of Fifths in the previous experiment, there were only two keys which had tonic triads built on degrees of the E-major scale, E major and A major. Moving in a clockwise direction for seven keys yields six keys which have tonic triads built on degrees of the E-major scale. These are E, B, F#, C#, Ab (actually G# in the key of E major), and Eb major (actually D# in the key of E major). If musicians are differentially sensitive to the tonics on which the triads are built, then the clockwise movement used in Experiment 4 would involve judgements of much more musically probable events. Subjects would now be judging six triads built on root-notes which were diatonic in the key of E major, and only one triad built on a root-note which was nondiatonic in the key of E major. It is important to note, however, that all triads presented in the experiments of the present thesis were major triads. Counterclockwise movement on the circle reveals only two major triads shared in the key of E major (E major and A major), whereas a clockwise movement also shows only two major triads shared with E major (E major and B major). In this way, if musicians are not only sensitive to the tonics on which the triads are built, but also to the type of chord (e.g., major, minor) that is built on that tonic, then Experiment 4 makes no more musical sense than Experiment 3 in terms of the diatonicism of the triads.

Given that some evidence for sensitivity to chordal relationships based on the Circle of Fifths had been obtained in Experiments 1, 2, and 3, Experiment 4 was conducted under the same paradigm as Experiment 3, except that chords were taken from clockwise movement on the Circle of Fifths. This span of keys included E, B, F#, C#, Ab, Eb, and Bb major, in which the three inversions of each tonic triad were presented. The 1E chord continued to be used as the standard chord, as in Experiment 3, and the keys of E and Bb major were still the most distant keys presented. Ordering of the chordal stimuli in terms of decreasing pitch-height from the 1E standard was as follows: 1E, 1Eb, 1C#, RE, 1B, REb, 1Bb, RC#, 1Ab, 2E, 2Eb, RB, 1F#, RBb, 2C#, RAb, 2B, 2Bb, RF#, 2Ab, 2F#, where R = Root, 1 = First Inversion, 2 = Second Inversion, and all other letter symbols refer to root-note.

Such a design does not address the potential problems posed by the use of such a large number of chords, or the use of triads too closely spaced in terms of key relatedness. It also does not address the use of a constant standard at one extreme of the pitch-height continuum that might encourage pitch-height judgements. Furthermore, it does not change the use of a constant standard to which a number of chords drawn from different keys must be related, when the general practice is to modulate between closely related keys. However, the fact that a weak root-note dimension did emerge in Experiment 3 led to the present speculation that a stronger root-note dimension might emerge if the stimulus set were constructed on the basis of the more usual clockwise movement between keys. Experiment 4 was conducted to test whether a change of direction would result in a better defined root-note dimension.

As in Experiment 3, only moderately-experienced and professional musicians were tested, as it was expected that only those with musical training would be able to perform on the basis of root-note, if indeed this was a strategy to be invoked at all.

Method

Subjects. Twenty-five individuals were recruited to serve as subjects. Seven of these subjects were enlisted from the McMaster University Symphony Orchestra; 3 were musicians in the Hamilton, Ontario community, who were referred by other professional musicians in Hamilton; 11 were recruited from an undergraduate introductory psychology course; 1 was a graduate student in the McMaster University Department of Psychology; 1 was a music major in the Department of Music; 1 was an undergraduate psychology student; and 1 was the experimenter herself. The subjects were grouped according to two experience levels, in accordance with the criteria specified in the earlier experiments: professional musicians and moderately-trained musicians. The professional group was comprised of 10 individuals, each of whom was paid $5 for participation. The training of these 10 subjects ranged from 2.8 to 12.0 years on their self-designated primary instruments (mean = 10.0 years). These 10 subjects reported theory training ranging from 0.0 years of study to having taken university level theory courses (3 subjects held one or more university degrees in music). All subjects played more than one instrument. Current musical involvement in the form of playing one's primary instrument, teaching, and studying music was reported at an average of 11.0 hours per week, while mean listening activity was reported at 3.2 hours per day. Nine of the 10 professionals reported family members who at sometime played a musical instrument. One of these subjects reported having absolute pitch. Of these 10 professional musicians, 5 were male and 5, female.

The training of the 15 subjects considered moderately trained ranged from 6.0 to 14.0 years on their self-designated primary instruments (mean = 9.2 years). Twelve of the subjects reported theory training (mean level attained = 2.0 years), and 13 of the subjects played more than one instrument. All of the subjects also reported participation in other musical activities such as band and choir at some time during their music studies. Current musical involvement in the form of playing one's primary instrument was reported at an average of 4.6 hours per week, while mean listening activity was reported at 2.8 hours per day. Thirteen of the 15 moderately-trained subjects reported family members who were at sometime involved with music. One reported absolute pitch. Of the 15 moderately-trained subjects, 4 were male and 11, female.

One of the professional subjects reported a 30% hearing loss in each of his ears. All other subjects reported normal hearing.

Apparatus. All apparatus was the same as in Experiments 1, 2, and

3.

Stimuli. Each trial consisted of the presentation of two pairs of chords. All tones comprising the chords were sine waves and were of equal temperament.

Chords presented in this experiment included the identical E-major and Bb-major chords in root, first inversion, and second inversion positions used in Experiments 1, 2, and 3. The E-major first-inversion triad, 1E, was designated as the standard chord for all trials. In addition, analogous positions were constructed for the other five triads which also served as chordal stimuli. These included the B-major root form (B: 493.9 Hz, D#: 622.3 Hz, F#: 740.0 Hz), first inversion (D#: 622.3 Hz, F#: 740.0 Hz, B: 987.8 Hz), and second inversion (F#: 370.0 Hz, B: 493.9 Hz, D#: 622.3 Hz); F#-major root form (F#: 370.0 Hz, A#: 466.2 Hz, C#: 554.4 Hz), first inversion (A#: 466.2 Hz, C#: 554.4 Hz, F#: 740.0 Hz), and second inversion (C#: 277.2 Hz, F#: 370.0 Hz, A#: 466.2 Hz); C#-major root form (C#: 554.4 Hz, E#: 698.5 Hz, G#: 830.6 Hz), first inversion (E#: 698.5 Hz, G#: 830.6 Hz, C#: 1108.7 Hz), and second inversion (G#: 415.3 Hz, C#: 554.4 Hz, E#: 698.5 Hz); Ab-major root form (Ab: 415.3 Hz, C: 523.3 Hz; Eb: 622.3 Hz), first inversion (C: 523.3 Hz, Eb: 622.3 Hz, Ab: 830.6 Hz), and second inversion (Eb: 311.1 Hz, Ab: 415.3 Hz, C: 523.3 Hz); and Eb-major root form (Eb: 622.3 Hz, G: 784.0 Hz, Bb: 932.3 Hz), first inversion (G: 784.0 Hz, Bb: 932.3 Hz, Eb: 1244.5 Hz), and second inversion (Bb: 466.2 Hz, Eb: 622.3 Hz, G: 784.0 Hz). Figure 32 contains the musical notation of these stimuli in order of increasing pitch-height across the stimulus set, and in order of increasing key distance from the

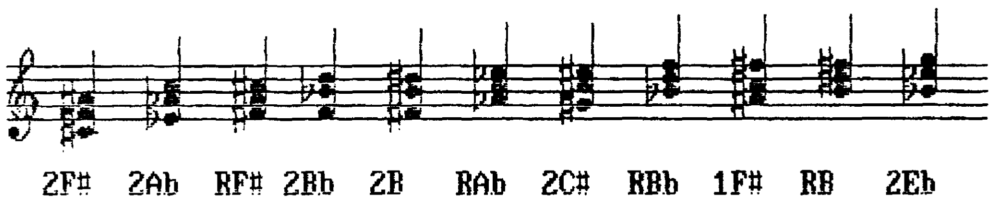
Figure 32. Musical notation of stimuli used in Experiment 4.

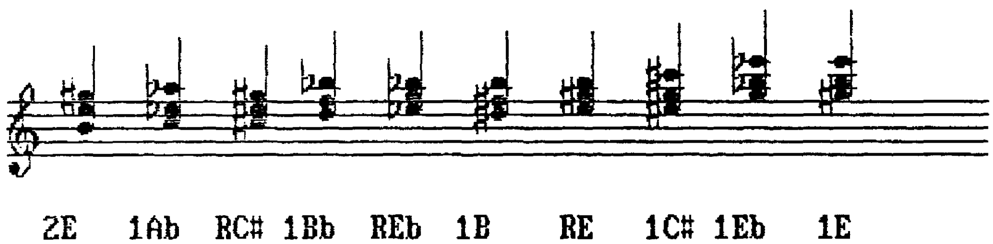
A: Triads presented in order of increasing pitch-height.

B: Triads grouped by common root-note.

(R = Root; 1 = First Inversion; 2 = Second Inversion; All other characters = Root Note)

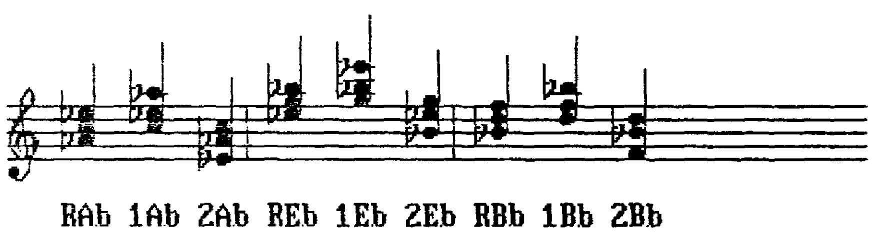
A


2F# 2Ab RF# 2Bb 2B RAb 2C# RBb 1F# RB 2Eb


2E 1Ab RC# 1Bb REb 1B RE 1C# 1Eb 1E

B


RE 1E 2E RB 1B 2B RF# 1F# 2F# RC# 1C# 2C#


RAb 1Ab 2Ab REb 1Eb 2Eb RBb 1Bb 2Bb

standard stimulus chord, 1E, on the Circle of Fifths.

The sampling rate for all nine stimulus chords was 20,000 Hz. To prevent aliasing, a low-pass filter cutoff was set at 10,000 Hz. Rise and fall times were set at 50-msec. Measurement with an artificial ear and SPL meter indicated all stimulus chord presentations to be at 72±1 dB SPL.

The fundamental roots for each of the stimulus chords were as follows: 165 Hz for the E-major chords; 123 Hz for the B-major chords; 92 Hz for the F#-major chords; 138 Hz for the C#-major chords; 103 Hz for the Ab-major chords; 155 Hz for the Eb-major chords; and 116 Hz for the Bb-major chords.

All duration parameters for the presentation of chords were the same as for Experiments 1, 2, and 3. Furthermore, the configurations and instructions presented on the monitor were identical to the earlier studies. There were three trial blocks. Subjects received a 5-min break from the experiment between each block.

Procedure. All procedural details were identical to Experiment 3.

Results

Correlation Analysis

As in Experiment 3, a preliminary correlation analysis was conducted to determine usage of either a root-note or pitch-height strategy. Spearman rank correlation coefficients were computed for each subject's ranked choice scores (based on the number of times each comparison chord was chosen as sounding similar to the standard) and the predicted ranks of choice scores for a strict key ordering according to the Circle of Fifths, and the predicted ranks of choice scores for a strict pitch-height ordering. The subject's ranked choice scores were computed by ranking the subject's comparison chord choices from 1 to 21, with 1 assigned to the chord chosen most often as sounding similar to the standard, and 21 assigned to the least-chosen chord. The confound between the Circle of Fifths ordering and the pitch-height ordering of the stimulus chords was $r_s = .14$. Table 2 presents these correlation results in descending order from the subject displaying the highest correlation with the Circle of Fifths ($r_s = .96$) to the subject with the lowest correlation ($r_s = .10$). The results were similar to Experiment 3, in that as the rank order correlations for subjects' ranked choice scores and the Circle of Fifths decreased, the correlations for pitch-height generally increased. Exceptions were evident, however, in that a few subjects showed high positive correlations that were nearly equivalent for pitch-height and the Circle of Fifths. Also, several subjects showed low positive correlations with both strategies, or a low negative correlation with one strategy and a low positive correlation with the other. These anomalies made it difficult to determine exactly what type of strategy might have been employed.

Regarding the professional musician who reported absolute pitch, his results were uninterpretable as to whether he relied more on pitch-height ($r_s = .61$) or root-note ($r_s = .74$), although his correlation results favored root-note. For the moderately-experienced subject claiming absolute pitch, her results stongly indicated a pitch-height strategy (pitch-height $r_s = .80$; root-note $r_s = .28$).

The professional who reported some hearing difficulties indicated a

Table 2

Experiment 4

SPEARMAN RANK ORDER CORRELATIONS FOR SUBJECTS' RANKED CHOICE SCORES AND PITCH-HEIGHT RANKS, AND SUBJECTS' RANKED CHOICE SCORES AND CIRCLE OF FIFTHS RANKS

(SUBJECTS SORTED ON BASIS OF DECREASING CIRCLE OF FIFTHS CORRELATIONS)

SUBJECT (E = MODERATELY EXPERIENCED; P = PROFESSIONAL)	PITCH-HEIGHT	CIRCLE OF FIFTHS
P	.06	.96
P	.25	.91
E	.41	.87
P	.22	.86
E	.23	.82
E	.16	.74
P	.61	.74
P	.75	.62
E	-.20	.55
E	.82	.46
E	-.52	.45
P	.88	.40
E	.90	.39
E	-.15	.36
E	-.41	.34
E	.92	.32
E	.96	.30
E	.80	.28
P	.94	.26
P	.94	.24
E	.89	.24
P	-.48	.17
E	.92	.16
E	.94	.12
P	.84	.10

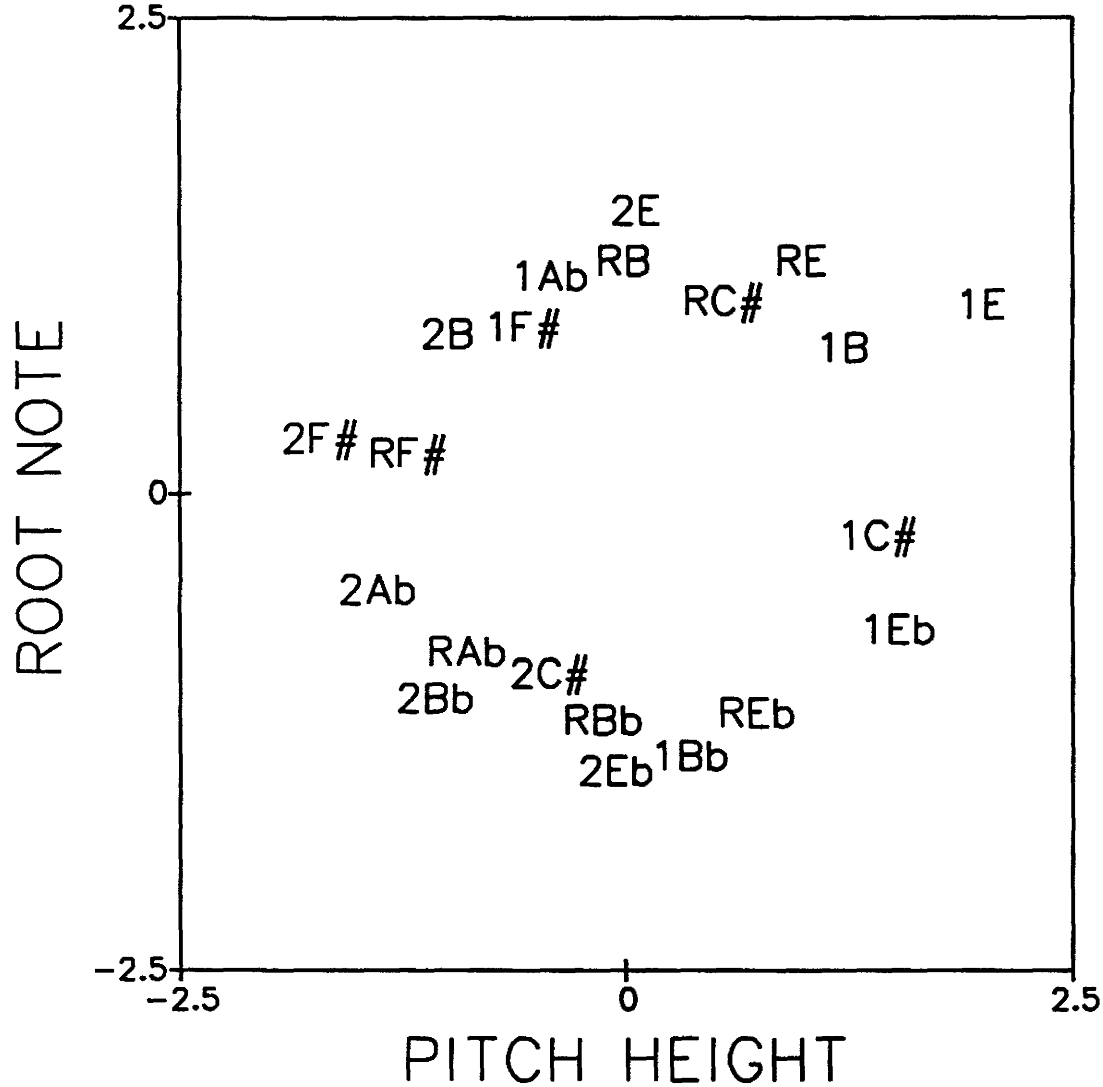
reliance on pitch-height (pitch-height r_s = .94; root-note r_s = .24).

Multidimensional Scaling

The main analysis of this experiment used the INDSCAL model of the multidimensional scaling program ALSCAL (Young, Takane, & Lewyckyj, 1978). The data matrices for each subject were arranged in an N x P format, in which N refers to the stimulus chord which served as the comparison in the first pair of chords, and P refers to the stimulus chord which served as the comparison in the second pair of chords. The entries within the matrices consisted of binary data, with 0 indicating a choice of the first comparison chord, and 1 indicating a choice of the second comparison chord. To the extent that a subject's pattern of choices for comparison chords presented in second pairs was similar for comparison chords presented in first pairs, those chords presented in first pairs would be assumed to have been perceived in a similar manner. In this way, it was actually the first-pair chords which were scaled in the scaling analysis. Before the scaling analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Simple Matching measure of binary association. The multidimensional scaling procedure described in Chapter II was then performed on these matrices. The two-dimensional solution, which accounted for 26% of the variance (S-STRESS = .485; STRESS = .359) was chosen because of the likelihood of making a plausible interpretation of the two dimensions, and because no clear elbow was detected in the STRESS by Dimensions graph for any of the two to six dimensions for which solutions were obtained. In Figure 33 is presented this two-dimensional solution, in which the two dimensions were interpreted as

Figure 33. Two-dimensional INDSCAL solution resulting from analysis of choice scores in Experiment 4.

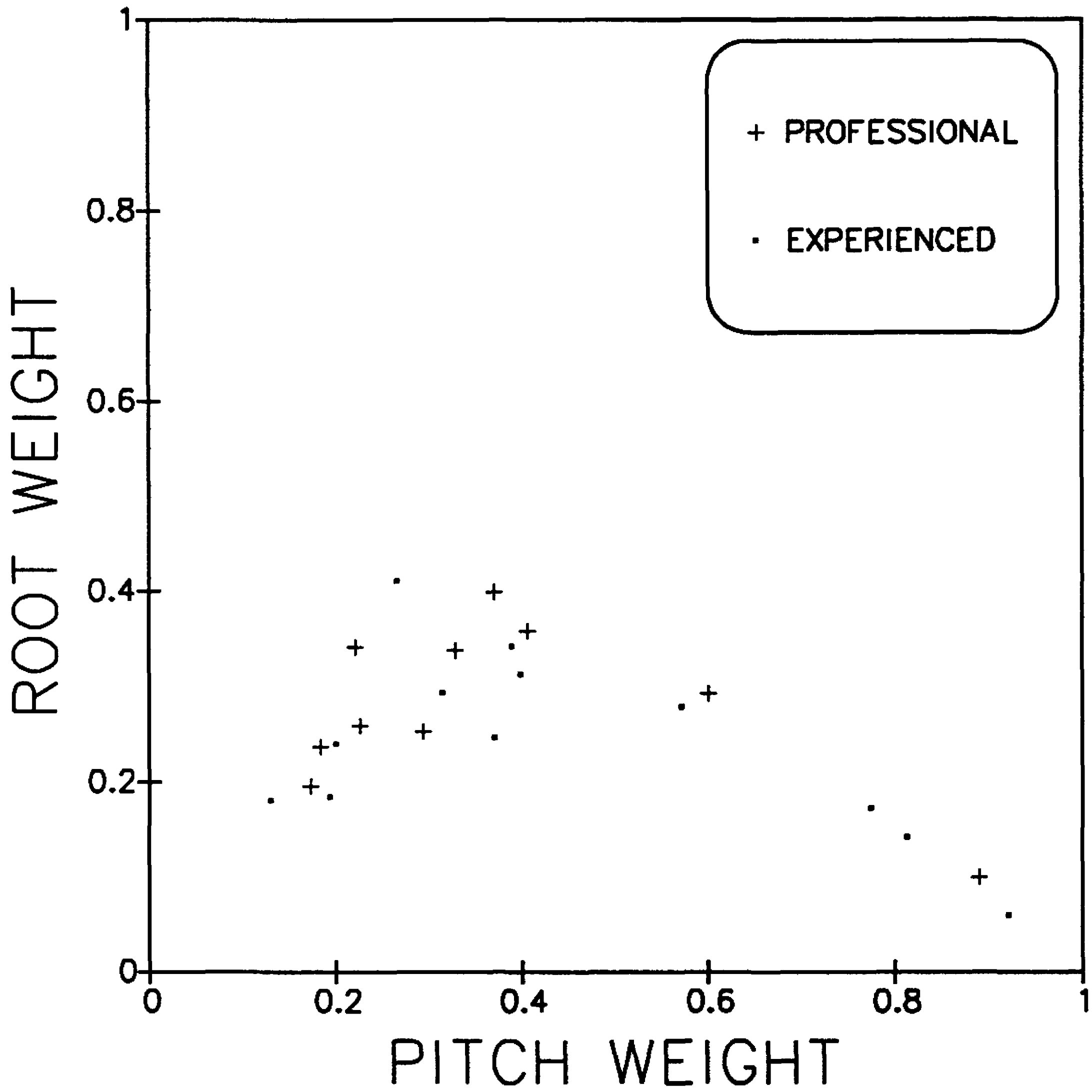
(R = Root; 1 = First Inversion; 2 = Second Inversion; All other characters = Root Note)


2.5
0
-2.5
-2.5
0
2.5
ROOT NOTE
PITCH HEIGHT
2E
1Ab
RB
RE
RC#
1E
2B
1F#
1B
2F#
RF#
1C#
2Ab
1Eb
RAb
2C#
2Bb
RBb
REb
2Eb
1Bb

representative of root-note and pitch-height strategies. Along the horizontal axis is shown the pitch-height dimension, in which the stimulus chords are generally ordered from low to high pitch-height. The root-note dimension, shown on the vertical axis, does not correspond perfectly to the root-notes of E, B, F#, C#, Ab, Eb, and Bb, the Circle-of-Fifths ordering predicted. Toward the top of the graph are the E- and B-major chords, which were most highly related to the 1E standard. At the bottom of the graph appear the Eb- and Bb-major chords, which were the most distantly related to the 1E standard. Between these two groupings of chords are the F#-, C#-, and Ab-major chords, which are intermediate in terms of relatedness to the E- and B-major grouping at the top of the graph, and the Eb- and Bb-major chord groupings at the bottom. The F#-major chords occurred closer to the E- and B-major chords, which would be expected on the basis of musical relatedness, and except for the first inversion Ab-major chord, the other two Ab chords appeared closer to the Eb- and Bb-major chords, which would also be expected in terms of musical relatedness. Except for the C#-major root chord, the C#-major chords were displayed in the general vicinity of the Ab-major chords, which would be expected in terms of the high degree of relatedness between their respective root-notes. In terms of relatedness to the entire set of stimulus chords, however, the C#-major chords would have been predicted to fall in a more intermediate position within the set of 21 stimulus chords.

Figure 34 presents the derived subject weights for the root-note and pitch-height dimensions. No apparent distinctions could be discerned between the moderately-trained and professional musicians regarding their usage of

Figure 34. Derived subject weights for 2-dimensional INDSCAL solution of Experiment 4.


PROFESSIONAL
EXPERIENCED
ROOT WEIGHT
PITCH WEIGHT
0
0.2
0.4
0.6
0.8
1

these strategies. No subject had particularly high weightings for the root-note dimension, whereas several displayed very high weightings for the pitch-height dimension. In general, except for several subjects showing low, nearly equivalent weightings on both dimensions, there was a trend for the weightings for root-note to decrease as those for pitch-height increased.

There was no evidence from the scaling solution that subjects had based their judgements on relative pitch-heights of the fundamental roots of the triads. The expected ordering of triads if they had followed this strategy would be: F#, Ab, Bb, B, C#, Eb, and E, where the fundamental roots were 92 Hz, 103 Hz, 116 Hz, 123 Hz, 138 Hz, 155 Hz, and 165 Hz, respectively.

Discussion

The results of Experiment 4, in which 21 chords were chosen in a clockwise manner around the Circle of Fifths and judged in terms of similarity to a standard E-major chord, were almost indistinguishable from the results of Experiment 3, in which the 21 chords were chosen in a counterclockwise direction. In both experiments, moderately-trained and professional musicians did not exhibit a strong root-note dimension, and could not be distinguished from one another in terms of differential strategy use. In fact, the RSQ, S-STRESS, and STRESS values were nearly identical for both experiments (Experiment 3: RSQ = 28%, S-STRESS = .477, STRESS = .352; Experiment 4: RSQ = 26%, S-STRESS = .485, STRESS = .359).

Given that the direction on the Circle of Fifths from which chords were chosen to be judged did not affect subjects' ability to judge key, it would appear that subjects were attending to the _type_ of triad (e.g., major, minor) presented as well as the relationships between the tonics on which each triad was built. If subjects had been attending to only the tonic relationships and judging chordal relationships on this basis, they would have been expected to give a clear ordering of the chords based on the Circle of Fifths. This result would be expected, given the more conventional clockwise movement around the circle, and the presentation of a number of chords whose tonics were diatonic in the key of E major. Alternatively, an ordering based on the chordal functions of the stimulus chords within the key of E major, rather than an ordering based on the Circle of Fifths, could have emerged. Such an ordering might have taken the form, E, B, C#, F#, Ab, Eb, Bb, which corresponds to the theoretic ordering of chords in terms of decreasing stability within a key (I, V, VI, II, III, VII, and a nondiatonic chord). This ordering is only slightly different from the Circle of Fifths ordering of the chords, in that the C# and F# chords are juxtaposed, but this ordering also reflects triad type (i.e., the I and V chords are considered to be major, the II, III, and VI chords are considered to be minor, and the VII chord is considered to be diminished). Neither the Circle of Fifths ordering nor the chordal function ordering for the key of E major were very clear, however, in the scaling analysis.

Because of the strong similarity between the results of Experiments 3 and 4, it was probably the case that for the subjects who based their judgements on the relationships between major triads, it did not matter whether these relationships were investigated through a modulation by fourths (counterclockwise) or by fifths (clockwise). In either case, only two major chords were diatonic with the standard key of E major, so it is quite remarkable that any ordering resembling the Circle of Fifths could be found.

Because of the somewhat close proximities in the scaling solution of triads sharing the same root-note, inversion equivalence was once again assumed to be demonstrated.

Conclusion

The highly-trained musicians in Experiment 4 were not found to exhibit strong root-note judgements when major tonic triads were selected in a clockwise direction from a standard chord on the Circle of Fifths. These results were similar to those of Experiment 3, where the triads were selected from a counterclockwise direction. There were a number of factors in both Experiments 3 and 4 that could have served as sources of confusion for triad similarity judgements. These included the large number of closely-spaced stimuli presented, the use of a constant standard at one extreme of the pitch-height continuum of stimulus chords, and the use of a standard, which is not traditional musical practice in modulations.

In Experiment 5, subjects were presented with 7 different Shepard chords, drawn from the same keys used in Experiment 4. The use of Shepard chords should eliminate pitch-height and inversion distractions, and would also decrease the number of chordal stimuli to be judged from 21 to 7 while still covering the same distance on the Circle of Fifths. Furthermore, because of the decrease in the number of stimuli to be used, presentation of the triads could be handled by the paradigm originally used in Experiments 1 and 2, where a roving standard chord was used. Such a design would supposedly eliminate a number of extraneous variables that could have confused subjects while they made triad-similarity judgements. Given these more favorable circumstances, only moderately-trained musicians were initially recruited for the study. If these subjects failed to show an orderly pattern of results, either in terms of root-note or pitch-height, then professional musicians would also be recruited.

CHAPTER VII

EXPERIMENT 5

To understand the rationale for Experiment 5 requires a review of the findings of Experiments 1-4 of the present thesis. In Experiment 1, triads from the maximally-related keys of A and E major were presented, and only professional musicians reliably judged chords as more similar if they were built on the same root-note. In Experiment 2, triads from Bb major were presented in addition to the A- and E-major triads, and a greater proportion of the moderately-trained musicians performed like the professionals, judging the triads on the basis of root-note. A number of these moderately-trained subjects, however, still did not make the distinction between the maximally- related A- and E-major triads. It was hypothesized that this was due to the multiple harmonic functions shared between these highly-related keys. In Experiments 3 and 4, where triads were presented which spanned half of the Circle of Fifths, only a few professionals and a few moderately-trained subjects ordered the chords on the basis of their Circle of Fifths relationships. This root-note ordering was not as clear as would be predicted, given the beliefs that major triads are strong instantiators of key and that highly-trained individuals possess the knowledge of chordal relationships needed to perform in this manner. The alternative pitch-height ordering, exhibited by both professionals and moderately-trained subjects, however, was also not very clear in these two experiments. One consistent finding across all four experiments, was that regardless of the ordering between chords built on different root-notes, chords built on the same root-note were generally grouped together. This result was taken as support for inversion equivalence amongst roots, first inversions, and second inversions with respect to key.

In an experiment conducted by Bharucha and Krumhansl (1983), they presented seven chords from the key of C major and seven chords from the key of F# major, two maximally-distant keys. Subjects rated how well one chord followed the other with no other musical context presented. When these results were subjected to a multidimensional scaling analysis, the solution showed a strong separation by key, and within each key there was a grouping of the I, IV, and V chords (all major chords) surrounded by the II, III, VI (all minor chords), and VII (a diminished chord) chords. Bharucha and Krumhansl's subjects (mean years playing an instrument or singing = 11.4) were no more experienced than the moderately-trained subjects employed in the present thesis, yet they were able to obtain a highly ordered pattern of results reflective of the chordal relationships predicted by music theory. One major difference, however, between the Bharucha and Krumhansl study and the present work was their use of Shepard chords as chordal stimuli. Perhaps the Shepard chords diminished the attributes of pitch-height and inversion so well, that subjects attended more to the overall chroma of the chords, and the multidimensional scaling solution revealed a sensible ordering of the chords according to music-theoretic principles. Of course, it must be realized that in this study the chords were drawn from two maximally-distant keys, which could have aided in their differentiation. Furthermore, the II, III, and VI chords were minor and the VII chord was diminished, possibly acting as important cues to the instantiation of key. The fact that such an orderly organization according to principles of chordal relationships within keys could be obtained though, does support musicians' awareness of the proposed chordal hierarchy when highly-related chords in the absence of more elaborate musical context are presented for judgement.

In Experiments 3 and 4 of the present thesis, the triads were built in the usual manner of three component tones played simultaneously. The musically-trained subjects did not exhibit orderly chordal groupings by musical key, but there were a number of possible sources of confusion confounded with presentation of the chordal stimuli. One source was the use of a constant standard chord. When a subject was presented with the standard followed by a comparison chord, that comparison chord could be built on any one of seven different root-notes, in any one of three inversions. Also, a subject could have attended to the pitch-heights of the chords. In this way, when a subject heard a standard chord followed by 1 of 21 different comparisons, there were at least two strategies a subject might use to judge the chords: pitch-height and root-note. If the root-note strategy was employed, there were at least two ways in which it could be invoked. The standard and comparison could be compared in terms of different inversions of a triad built on the same root-note, and could also be compared in terms of key distance between their root-notes.

Although subjects were shown in Experiment 2 to perform like Bharucha and Krumhansl's (1983) subjects for maximally-distant keys, and although very highly-trained subjects were shown to be able to separate maximally-related keys in Experiments 1 and 2, it may be that Experiments 3 and 4 attempted to add too many chordal dimensions at once. There were 21 chords that could be ordered on the basis of a number of dimensions, including root-note, pitch-height, or inversion. Furthermore, the use of a constant standard, which was originally intended to make judgements easier, since a single contextual key would be established, may have made the task much more difficult. The constant standard required subjects to decide on seven different placements on the Circle of Fifths in which each comparison chord had to be judged with respect to the standard chord.

Despite the adverse conditions in these earlier experiments, some subjects still managed to judge the chords on the basis of root-note, and place these chords in an order described by the Circle of Fifths. Experiment 5 was therefore conducted in such a manner as to eliminate some of these impediments to root-note judgements, while examining several theoretical beliefs: (1) musicians possess an underlying representation of chordal relationships; (2) this representation is organized by musical fifths; (3) the representation can be accessed if the musical circumstances are conducive to it; and (4) presentation of isolated major triads is enough musical context to access the representation. In Experiment 5, therefore, Shepard chords were selected from all the keys used in Experiment 4: E, B, F#, C#, Ab, Eb, and Bb major. The use of Shepard chords would attenuate inversion and pitch-height cues as sources of confusion. Evidence for inversion equivalence had been obtained in Experiments 1-4, and it was not felt that it needed to be tested further in

Experiment 5. Also, it was felt that by eliminating pitch-height as a possible cue, subjects might access a root-note strategy more easily, or alternatively, might give uninterpretable results if a root-note strategy was not available to them. The use of Shepard chords might also lessen the difficulty of the task by decreasing the number of stimuli from 21 to 7. Furthermore, Experiment 5 employed the use of a roving standard chord, as in Experiments 1 and 2. In this way, a greater proportion of the trials would involve judgements between closely-related keys (keys either a musical fourth or fifth away from the standard), whereas with the constant standard only judgements between the standard and the adjacent key on the Circle of Fifths involved judgements of closely-related keys.

Only moderately-trained subjects were initially tested. Furthermore, since the instruction to judge "similarity" of the triads is an ambiguous instruction with regard to musical attributes, half of the subjects were given a different instruction and asked to choose the pair of chords in which the "second chord best follows the first in a musical sense." This second instruction is much more similar to that used by Krumhansl and her colleagues, in which reasonable orderings based on music-theoretic principles had been obtained (Bharucha & Krumhansl, 1983; Castellano, Bharucha, & Krumhansl, 1984; Krumhansl, 1979; Krumhansl, Bharucha, & Castellano, 1982; Krumhansl, Bharuchal, & Kessler, 1982; Krumhansl & Keil, 1982; Krumhansl & Kessler, 1982; Krumhansl & Shepard, 1979). If an organized root-note result still was not obtained, professional musicians were to be recruited.

Method

Subjects. Twenty-eight individuals served as voluntary subjects. Twenty-seven of these subjects were recruited from an undergraduate introductory psychology course, and the remaining subject was the experimenter herself. All subjects were classified as moderately-trained musicians.

Fourteen of the subjects, including the experimenter, received the instruction to "choose the pair (on a trial) in which the two chords sound most similar," and were reminded that they should judge the similarity of the second chord in relation to the first. The remaining 14 subjects were told to "choose the pair (on a trial) in which the second chord best follows the first in a musical sense." The formal training of the subjects receiving the "similarity" instruction ranged from 3.0 to 13.0 years on their self-designated primary instruments (mean = 7.4 years). All of the subjects reported theory training (mean level attained = 2.5 years), and 11 of the subjects played more than one instrument. All 14 subjects also reported prior participation in other musical activities such as band and choir. Current musical involvement in the form of playing one's primary instrument was reported at an average of 3.6 hours per week, while mean listening activity per day was reported at 3.4 hours. Eleven subjects reported family members who at some time played a musical instrument. No subject reported having absolute pitch. Of these 14 subjects, 4 were male and 10, female.

The training of the subjects given the "musicality" instruction ranged from 3.0 to 13.0 years on their self-designated primary instruments (mean = 6.6 years). Ten of the subjects reported theory training (mean level attained = 1.6

years), and 13 of the subjects played more than one instrument. All 14 subjects reported prior participation in other musical activities such as band and choir. Current musical involvement in the form of playing one's primary instrument was reported at an average of 3.2 hours per week, while mean listening acitivity per day was reported at 2.9 hours. Eleven subjects reported family members who at some time played a musical instrument. One subject reported having absolute pitch. Of these 14 subjects, 4 were male and 10, female.

All subjects reported normal hearing.

Apparatus. All apparatus was the same as in Experiments 1, 2, 3, and 4, except that 6 of the subjects in the "similarity" instruction group listened to the stimuli through Realistic Pro-1 Headphones. This change was a result of modifications made to some other laboratory equipment for other experiments in the music laboratory. The new headphones were not found to alter the stimuli in any appreciable way, nor were the results of subjects who listened to the stimuli over these headphones distinguishable from any other subjects within the "similarity" instruction group.

Stimuli. Each trial consisted of the presentation of two pairs of chords. The tones comprising the chords were sine waves and were of equal temperament.

All chords were presented as Shepard chords, originally described in Experiment 1; however, they were not constructed in exactly the same manner. The chords in the present experiment were built by sampling the three tone components comprising the triads over a 6 octave range, from 55 Hz to 3520 Hz, resulting in 18 components for each chord. These sinusoidal components were sampled from under a cosine envelope centered at 440 Hz. The shape of the amplitude envelope, described by Deutsch (1987), was determined by the formula,

$$A(f) = 0.5 - 0.5 \cos [2\pi/\gamma \log_{\beta}(f/f_{min})] \quad f_{min} \leq f \leq \beta^{\gamma} f_{min},$$

"where A(f) is the relative amplitude of a sinusoid at frequency of f Hz, β is the frequency ratio formed by adjacent sinusoids (so that for octave spacing, $\beta = 2$), γ is the number of β cycles spanned, and f_{min} is the minimum frequency for which the amplitude is nonzero" (p. 565). Seven Shepard chords were constructed, one for each of the seven major keys spanning half of the Circle of Fifths. These included E (E, G#, B), B (B, D#, F#), F# (F#, A#, C#), C# (C#, E#, G#), Ab (Ab, C, Eb), Eb (Eb, G, Bb), and Bb (Bb, D, F) major triads.

The sampling rate for all seven stimulus chords was 20,000 Hz. To prevent aliasing, a low-pass filter cutoff was set at 10,000 Hz. Rise and fall times were set at 50 msec. Measurement with an artificial ear and SPL meter indicated all the stimulus chord presentations to be at 72±1 dB SPL.

The fundamental roots for the stimulus triads were: 20.60 Hz for E major; 15.43 Hz for B major; 23.13 Hz for F# major; 17.32 Hz for C# major; 25.96 Hz for Ab major; 19.44 Hz for Eb major; and 14.57 Hz for Bb major.

Given the longer times needed for the computer to construct the Shepard chords, longer duration parameters than those used in the preceding experiments were needed for presentation of the stimuli, and for the intra- and inter-pair intervals. This was to allow enough time for the chords to be constructed, and to make the longer stimuli sound as if they were separated into two distinct pairs. A trial consisted of a 0.75-sec presentation of a chord, followed by a 0.75-sec pause, and then another presentation of a 0.75- sec chord. This represented the first pair of chords. The first pair was separated from the second pair by a 1.50-sec pause, and the same duration parameters were applied to the second pair (0.75-sec chord followed by 0.75- sec pause, followed by 0.75-sec chord). The configurations and instructions presented on the monitor remained the same as in the four earlier studies.

There were two trial blocks. Subjects received a 5-min break from the experiment between the blocks.

Procedure. A paired-comparison paradigm was employed for presentation of the 7 chordal stimuli. A condition of the chord presentations demanded that the first stimulus of each pair on a trial was always the same chord. Further, the second chords of each pair could be any one of the seven stimuli as long as the two were not identical on a trial. After each of the seven chords was presented in every possible order and combination with all seven chords, in compliance with the conditions stated above, a total of 294 trials (147 trials per trial block) resulted. Each presentation order of trials was randomized for each subject. Subjects receiving the "similarity" instruction were given the same judgement instruction as in Experiments 1-4. That is, these subjects were told to choose the pair on a trial in which the two chords sounded "most similar" to each other. Subjects receiving the "musicality" instruction were told to choose the pair of chords in which the "second chord best follows the first in a musical sense." All subjects were warned that the first chord of each pair within trials would be the same chord, but that across trials this standard chord would often change. All other procedural details were identical to

Experiments 1-4.

Results

Hierarchical Clustering

A preliminary analysis of the similarity judgements for each subject was conducted using a Group Average Hierarchical Clustering technique (Edmonston, 1985). The data matrix for each subject consisted of choice scores, or the number of times each stimulus chord was chosen as sounding similar to each standard chord. Each matrix was arranged in an N x P format, in which N refers to the stimulus chords when they served as standard chords, and P refers to the stimulus chords when they served as comparison chords. To the extent that standard chords showed similar patterns of choices for comparison chords, those standards would be assumed to have been perceived in a similar manner. Before the cluster analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Euclidean distance formula. The cluster analysis procedure described in Chapter II was then performed on each of these matrices. Of the 14 subjects who received the instruction to judge the "similarity" of the stimulus chords, 4 appeared to have made their judgements on the basis of root-note; 3 appeared to have made partial use of a root-note judgment scheme, but occasionally grouped chords together which had fundamentals of similar pitch-height; 2 apparently used a pitch-height strategy in which the chords were judged as similar if their fundamentals were of similar pitch-height; and 5 subjects' results were uninterpretable with respect to any particular strategy they might have been using.

For the 14 subjects given the "musicality" instruction, 5 used a root-note strategy; 4 used a root-note strategy in which a chord or two fell out of the predicted Circle-of-Fifths ordering, but the anomaly was not attributable to the subject using a pitch-height strategy; 1 subject ordered the chords on the basis of pitch-height of the fundamentals, although the ordering was not perfect; and 3 subjects' results were uninterpretable.

A sample dendrogram for each of these categories of subjects within both the "similarity" and "musicality" judgement groups are included in Figures 35 and 36, respectively.

For subjects who made so-called judgements of pitch-height with the Shepard chords, it could not be distinguished whether they were attending to the root-notes of the chords and judging two chords as similar if their roots were close on the chromatic scale, or the frequency of the fundamentals, since an identical ordering of the chords would be expected in either case: Bb, B, C#, Eb, E, F#, Ab.

For the one subject in the "musicality" group who reported absolute pitch, her results indicated a Circle of Fifths ordering of the chords, which was similar to all other subjects displaying this type of result in this group.

Multidimensional Scaling

The main analysis of this experiment used INDSCAL, an individual differences model in the multidimensional scaling program ALSCAL (Young, Takane, & Lewyckyj, 1978). The data matrix for each subject was organized in a similar manner to those used for the cluster analysis, in an N x P format, with N referring to the stimulus chords when they served as standard chords, and P

Figure 35. Sample hierarchical clustering solutions from Experiment 5, using Group Average Method, for subjects receiving the "similarity" instruction. All subjects were classified as moderately trained.

A: Dendrogram for one subject who grouped the chords by root-note.

B: Dendrogram for one subject who displayed clusters giving some indication ofsensitivity to root-note.

C: Dendrogram for one subject who clustered the chords by pitch-height.

D: Dendrogram for one subject whose results were uninterpretable.

(Chord labels refer to the fundamental/root on which each Shepard chord was built.)

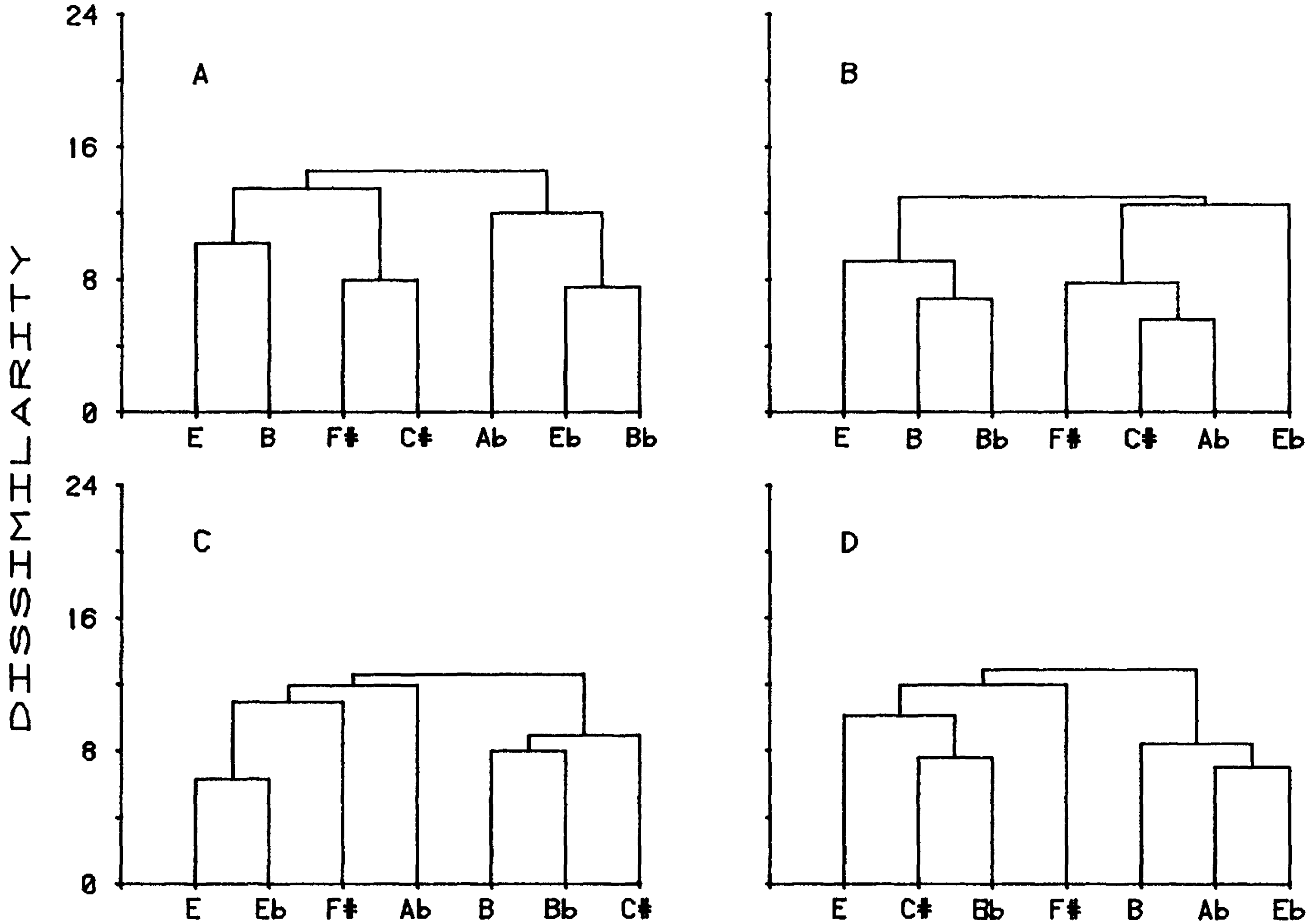

DISSIMILARITY
24
16
8
0
A
E B F# C# Ab Eb Bb
B
E B Bb F# C# Ab Eb
C
E Eb F# Ab B Bb C#
D
E C# Bb F# B Ab Eb

Figure 36. Sample hierarchical clustering solutions from Experiment 5, using Group Average Method, for subjects receiving the "musicality" instruction. All subjects were classified as moderately trained.

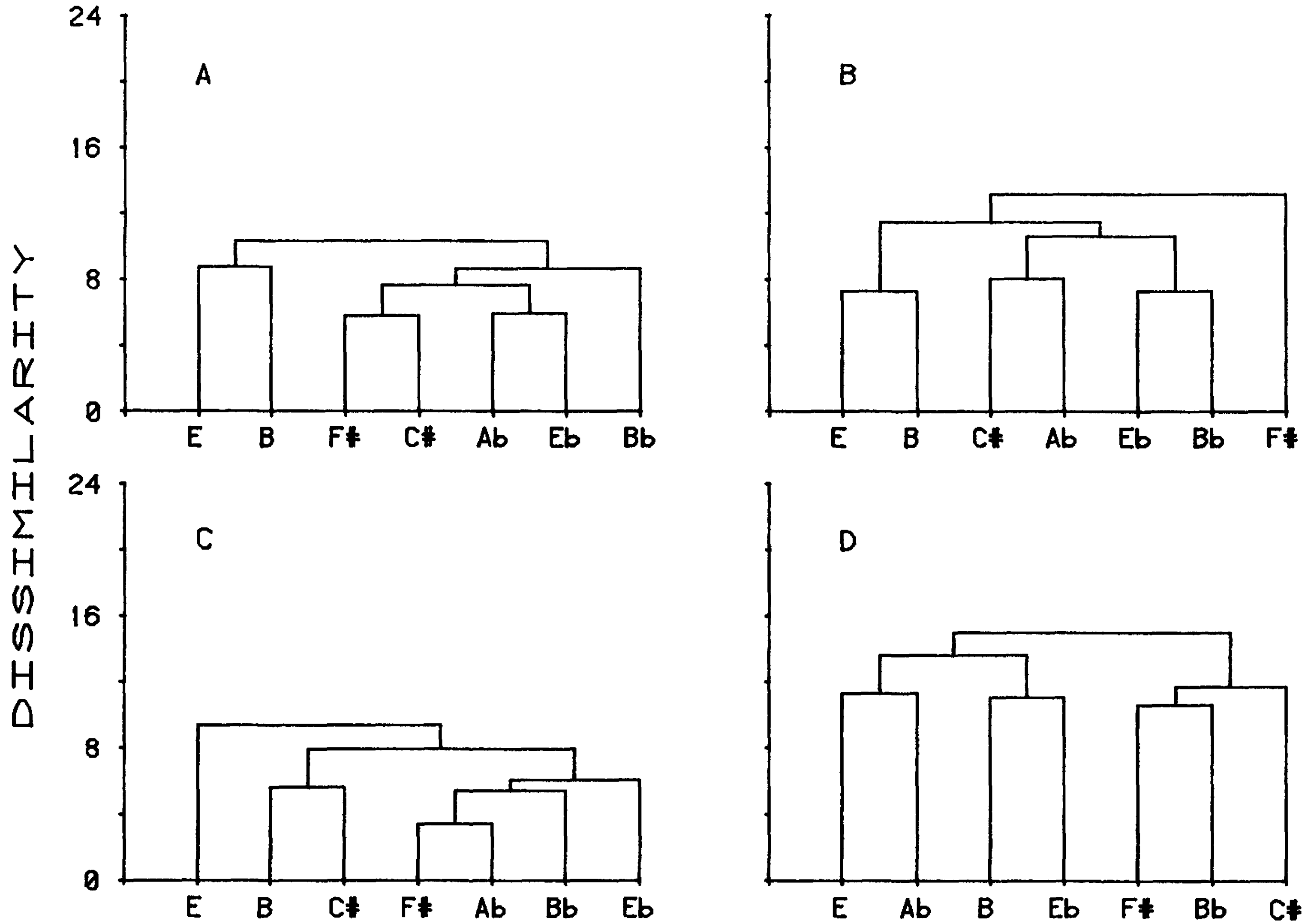
A: Dendrogram for one subject who grouped the chords by root-note.

B: Dendrogram for one subject who displayed clusters giving some indication of sensitivity to root-note.

C: Dendrogram for one subject who clustered the chords by pitch-height.

D: Dendrogram for one subject whose results were uninterpretable.

(Chord labels refer to the fundamental/root on which each Shepard chord was built.)


DISSIMILARITY
24
16
8
0
A
E B F# C# Ab Eb Bb
B
E B C# Ab Eb Bb F#
C
E B C# F# Ab Bb Eb
D
E Ab B Eb F# Bb C#

233

referring to the stimulus chords when they served as comparison chords. The matrices differed from the clustering matrices in that binary data comprised the entries, rather than the total number of times a comparison chord was chosen as sounding similar to a standard chord. A 0 was entered if the comparison chord of the first pair of chords was chosen, and a 1 was entered if the comparison chord of the second pair was chosen. To the extent that standard chords revealed a similar pattern of choices for the comparison chords, the standards would be assumed to have been perceived in a similar manner. Before the scaling analysis could be performed, each data matrix was transformed into a dissimilarity matrix through use of the Simple Matching measure of binary association. The multidimensional scaling procedure described in Chapter II was then performed on each of these matrices. The two-dimensional solutions were chosen for presentation for each of the instruction groups. The dimensionality was decided on the basis of interpretability, and on the basis of Davison's (1983) cautioning remark that at least three stimuli should be included within a stimulus set for each dimension predicted in the scaling solution. Given the seven stimuli of the present experiment, it was perhaps futile to obtain solutions for more than two dimensions, and examination of the STRESS by Dimensions graph did not reveal a clear elbow at any of these dimensionalities.

The subjects receiving the "similarity" instruction had only 28% of their variance accounted for, compared to 41% for those receiving the "musicality" instruction. Furthermore, the "similarity" subjects had higher S-STRESS and STRESS values (S-STRESS = .406; STRESS = .326) than the "musicality" subjects (S-STRESS = .365; STRESS = .291). Both two-dimensional solutions, shown in Figures 37 and 38, resulted in a roughly semi-circular configuration, in which the ordering of the stimulus chords reflected that represented by the Circle of Fifths: E, B, F#, C#, Ab, Eb, Bb. Davison (1983) warned that C- or U- shaped two-dimensional solutions are often best interpreted as solutions in one dimension. Kruskal and Wish (1978) also acknowledged the occurrence of this "horseshoe phenomenon," and advised that stimuli falling in such a pattern be considered as a one-dimensional solution. Because the stimuli in the present experiment fell in a highly interpretable order along one dimension, the solution was accepted as a one-dimensional ordering of the stimuli along one-half of the Circle of Fifths. The two solutions can be viewed as a 180^0 rotation of one another, with the "musicality" solution (Figure 38) appearing somewhat more orderly since only the B- and E-major chords are juxtaposed with respect to the Circle of Fifths, whereas the "similarity" solution (Figure 37) showed the additional juxtaposition of the Eb- and Bb-major chords.

Figures 39 and 40 present the derived subject weights for the subjects receiving the "similarity" and "musicality" instructions, respectively. As shown in both figures, there is a positive relationship between the weightings on Dimensions 1 and 2, with the subjects depicted in order from those whose data were not fit well by the model, as indicated by low RSQ values, to those whose data were fit very well by the model. This pattern lends credence to the assumption that the two-dimensional

Figure 37. Two-dimensional INDSCAL solution resulting from subjects who received the instruction to judge "similarity" in Experiment 5.

(Characters refer to root-notes of Shepard chords.)

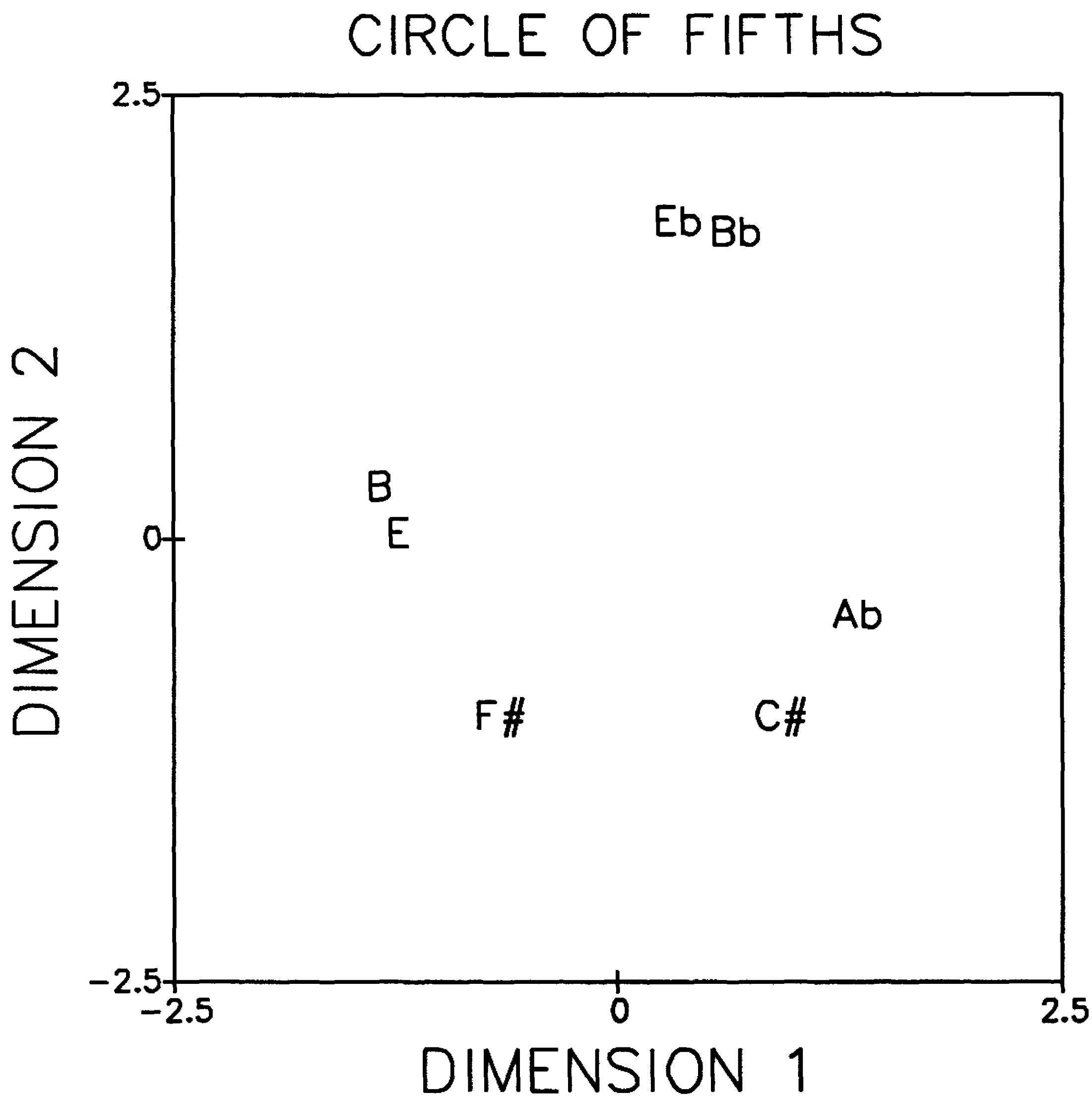

CIRCLE OF FIFTHS
2.5
0
-2.5
-2.5
0
2.5
DIMENSION 2
DIMENSION 1
Eb
Bb
B
E
Ab
F#
C#

Figure 38. Two-dimensional INDSCAL solution resulting from subjects who received the instruction to judge "musicality" in Experiment 5.

(Characters refer to root-notes of Shepard chords.)

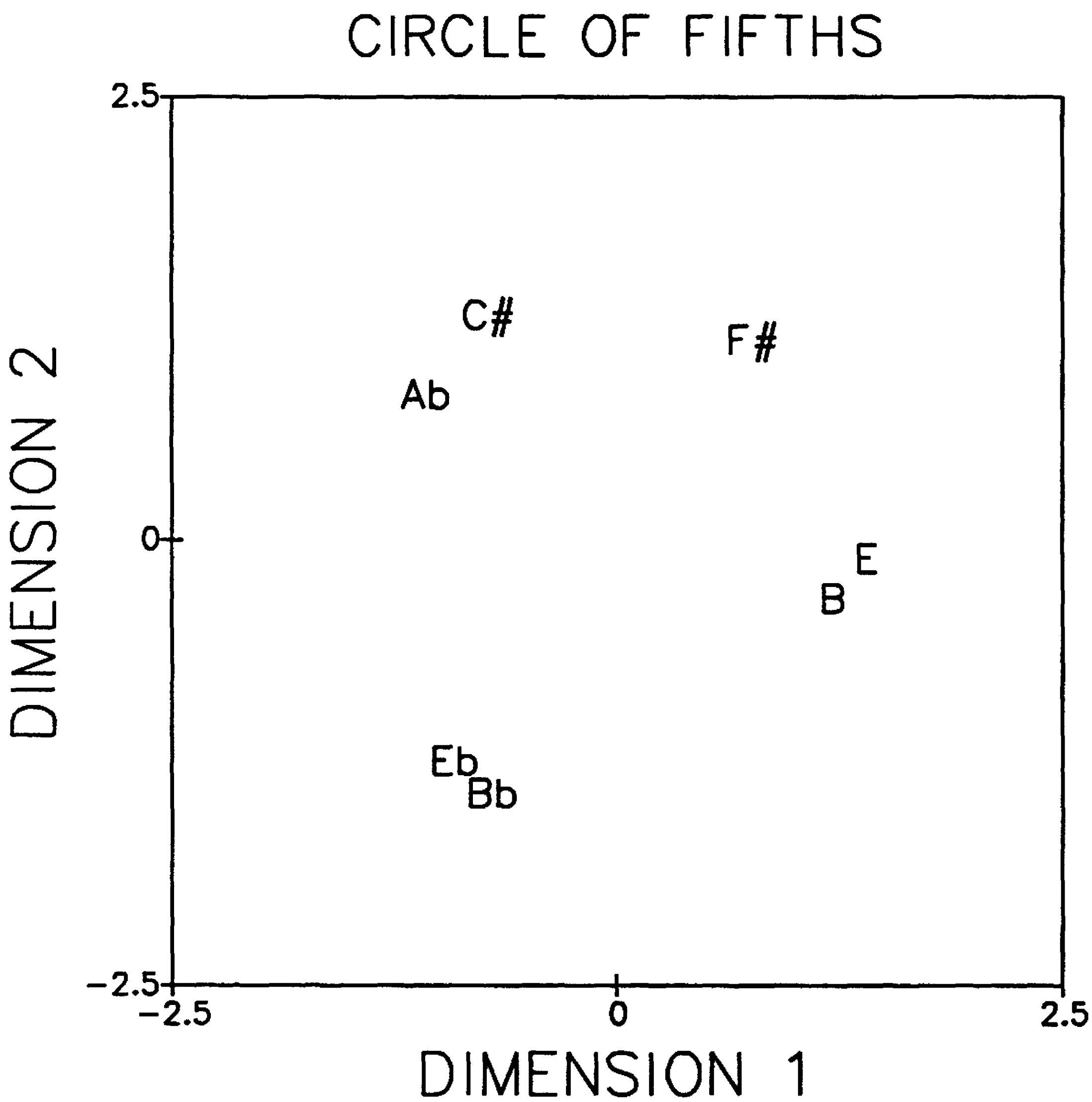

CIRCLE OF FIFTHS
2.5
0
-2.5
-2.5
0
2.5
DIMENSION 2
DIMENSION 1
C#
F#
Ab
E
B
Eb
Bb

Figure 39. Derived subject weights for 2-dimensional INDSCAL solution of Experment 5, in which subjects were instructed to judge "similarity."

(Individual RSQ values are shown for each subject.)

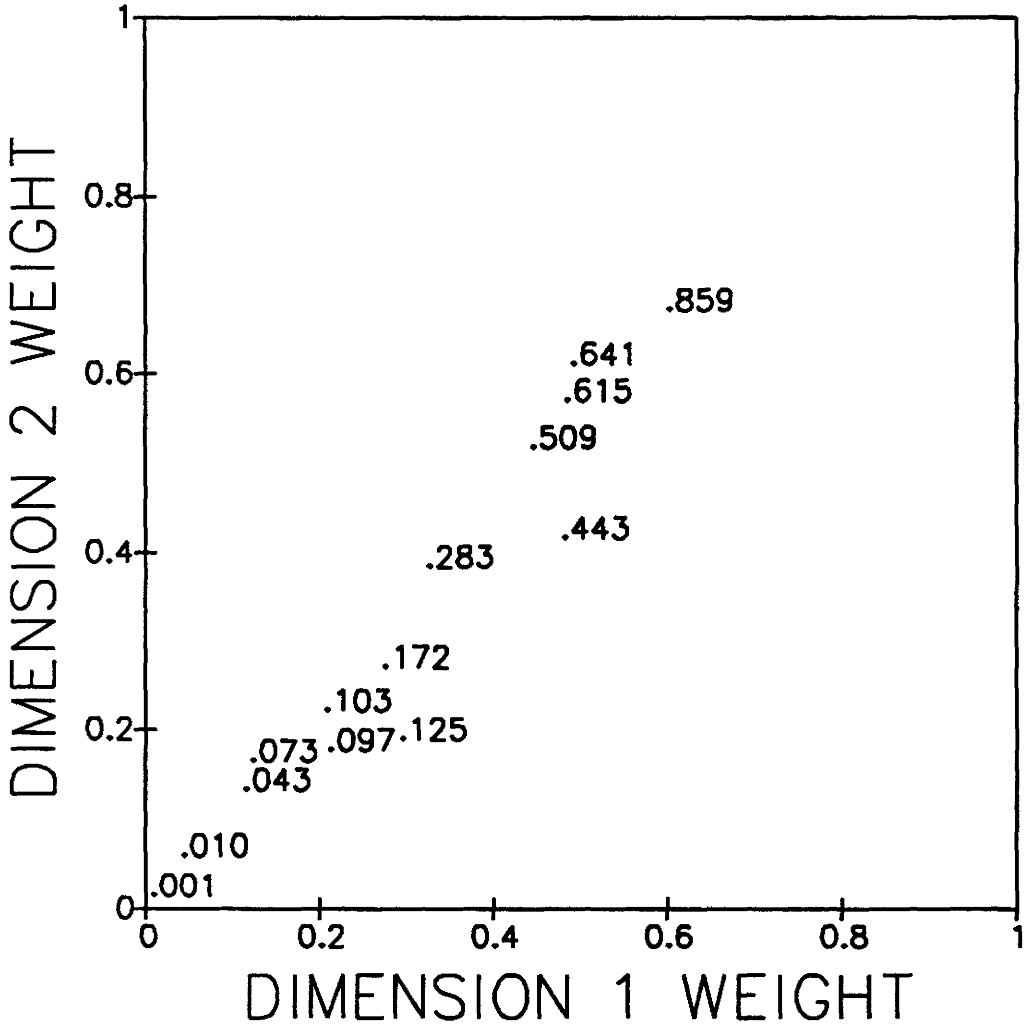
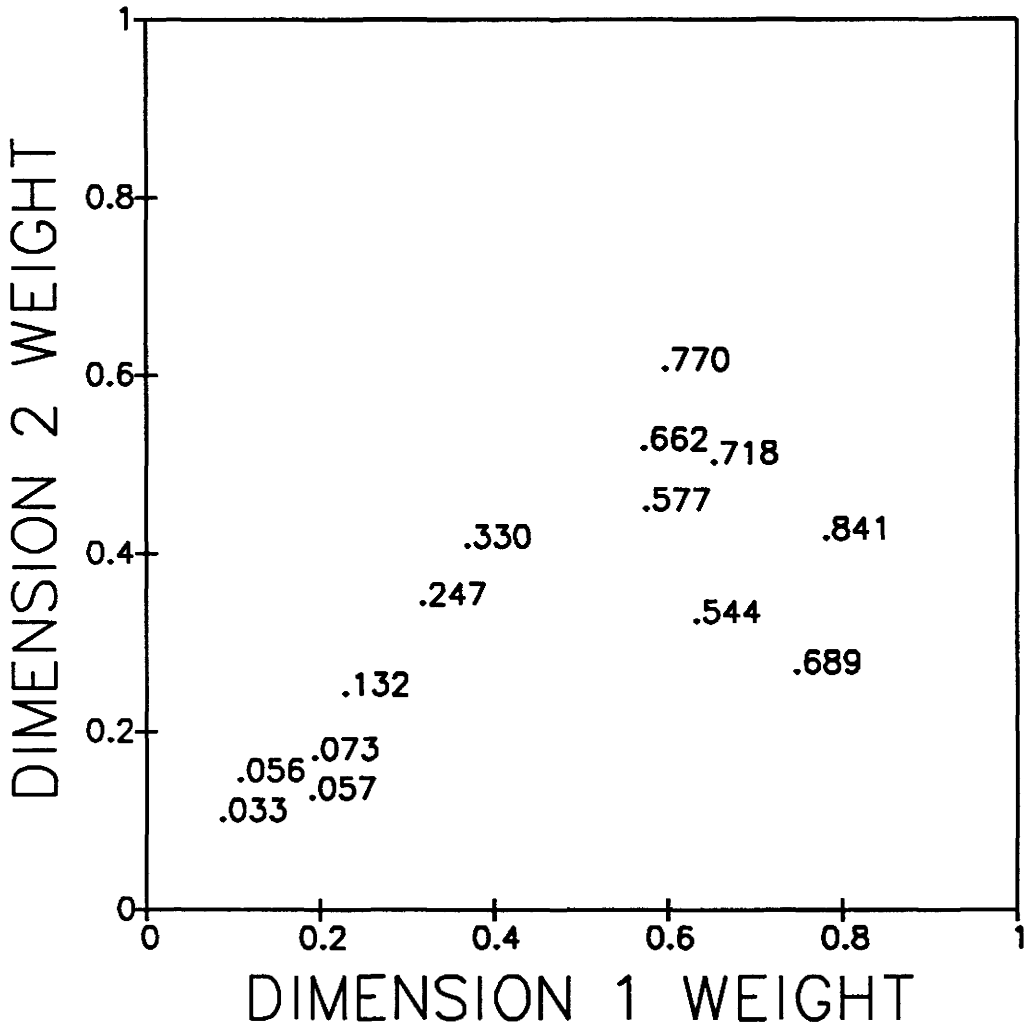

1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
DIMENSION 2 WEIGHT
DIMENSION 1 WEIGHT
.859
.641
.615
.509
.443
.283
.172
.103
.097
.125
.073
.043
.010
.001

Figure 40. Derived subject weights for 2-dimensional INDSCAL solution of Experment 5, in which subjects were instructed to judge "musicality."

(Individual RSQ values are shown for each subject.)



1
0.8
0.6
0.4
0.2
0
DIMENSION 2 WEIGHT
.770
.662
.718
.577
.841
.330
.247
.544
.689
.132
.073
.056
.057
.033
0
0.2
0.4
0.6
0.8
1
DIMENSION 1 WEIGHT

solution obtained in this analysis was actually representative of a one-dimensional solution, since no subject's weights were particularly high on one dimension relative to the other. It is evident in the figures that the data of a greater number of subjects' were fit by the model if they were given the "musicality" instruction.

Discussion

The results of Experiment 5 indicate that when Shepard chords built on seven different root-notes spanning one-half of the Circle of Fifths were presented to moderately-trained subjects, these subjects ordered the chords on the basis of the music-theoretic Circle of Fifths. Such a pattern emerged whether subjects were given the instruction to judge "similarity" or "musicality" of the chords, although the ordering was somewhat clearer for those receiving the musicality instruction.

Regarding the differential instructions given subjects, the more specific instruction to judge "musicality" of the chord sequence may have been the impetus to encourage stronger root-note judgements. Subjects in both instruction groups had a substantial amount of musical training, and would be expected to be flexible in terms of strategy usage. Giving the more specific instruction may have been enough to direct them toward root-note judgements and away from those of pitch-height.[7]

That such an orderly result reflective of theoretical chordal relationships could be obtained in moderately-trained subjects, showed that these individuals possess a knowledge of chordal functions in terms of key-relatedness, and that they can access them when presented with no musical context beyond that of major triads. It was perhaps the provision of more favorable circumstances for chordal judgement in this experiment--Shepard chords reducing pitch-height and inversion cues, a smaller number of stimuli to be judged, the use of a roving standard--which allowed recovery of a sensible configuration in terms of the theoretical relationships between chords built on different root-notes. Unfortunately, because a number of variables had been changed between Experiments 3 and 4 and the present experiment, it cannot be concluded which changes were most influential to the recovery of the Circle of Fifths. The Shepard chords reduced pitch-height and inversion cues, while establishing a strong sense of chroma. Also, a smaller number of chordal stimuli were presented within the context of the experiment, perhaps allowing subjects to form a clearer idea of the relationships between the chordal stimuli to be presented to them, both in terms of pitch-height and key-distance. The roving standard perhaps made judgements between chords easier, since chords from seven different keys would not have to be perfectly ordered in relation to one standard. Furthermore, with a roving standard, a number of the chordal judgements would be between closely-related keys, and as Krumhansl and Kessler (1982) demonstrated, subjects have pre-formed expectations for close modulations to occur. In order to sort-out which factors contributed most to these root-note judgements, a number of experiments could be methodically conducted, with only one factor manipulated in each experiment. The acknowledgement of these confounds, however, should not diminish the significance of the Circle of Fifths result found in the present experiment. Moderately-trained musicians demonstrated the ability to exhibit a strong Circle of Fifths ordering when major triads, in the absence of more elaborate musical cues to key, were presented.

Conclusion

Moderately-trained musicians, when presented with major triads in the form of Shepard chords, were able to order the chords on the basis of their Circle of Fifths relationships. The specific instruction to judge "musicality" resulted in a clearer scaling solution and accounted for more of the variance in the data, as compared to an instruction to judge the "similarity" of the chords. Evidence was provided in this experiment for major triads as instantiating key, in the absence of musical context beyond that of major triads, and empirical evidence was gained that these relationships can be accounted for by the theoretical Circle of Fifths.

CHAPTER VIII

GENERAL DISCUSSION

> "Musical cognition involves the creation of elaborate rhythmic and tonal structures, which may be formally described in grammatical terms; but the realisation of these structures in sound and their recreation by the listener involve skills and sensibilities of a delicacy that the psychologist of music is only beginning to appreciate."
> (Longuet-Higgins, 1985, p. xi)

For sounds to be perceived as musical requires structure. Music emerges from the complex interplay of relationships between sounds combining to form patterns, patterns which, through enculturation, an individual learns to recognize as musical. Psychomusicologists have tried to discover the underlying structures necessary for musical meaning, and to determine the types of individuals who are sensitive to these structures.

Music theory offers a wide selection of experimentally accessible principles of musical organization which can be tested for their perceptual/cognitive relevance. Although music theory has usually followed musical practice, it is an interesting question as to whether theoretic principles are descriptors of the capacities and limitations of the perceptual system, or whether the system is modified to be able to respond in the musically appropriate manner, as dictated by theory.

In the present thesis, the perception of major triads was chosen as an isolated, rudimentary element of music processing in which to examine a number of theoretical structures for their perceptual validity. As early as the eighteenth century, it had been accepted that certain relationships between tones, such as those tonal relationships found in major triads, should imply the percept of a particular fundamental chroma. Strong theoretical notions subsequently developed regarding the manner in which chords generating different fundamentals should be perceived by the musically skilled, yet it was not clear whether musically-untrained individuals were expected to perceive triads in a similar way. It could be the case, for example, that the musically unsophisticated would find another aspect of the chords, such as absolute pitch-height, to be a more salient dimension. It was the purpose of the present investigations, therefore, to examine the perception of major triads as a function of level of musical training. Support was gained in these studies for the music-theoretic notions of inversion equivalence, triads as instantiators of key in the absence of other musical cues to key, such as scales and melodies, and relationships of musical keys based on the Circle of Fifths for musically-trained subjects. Subjects lacking in formal musical background judged the chordal stimuli on the less-musical aspect of pitch-height.

The results of Experiments 1-4 indicated inversion equivalence amongst experienced musicians with respect to key. This was shown by the clusters of triads built on the same root-notes, in both the resultant dendrograms from cluster analysis (Experiments 1 and 2), and resultant configurations from multidimensional scaling (Experiments 1, 2, 3, and 4). Musically-inexperienced individuals demonstrated that the dimension of pitch-height was more salient to them. The differential significance of these two dimensions for musically-experienced and inexperienced individuals is supportive of Terhardt's (1974; 1978; 1984) theory of the importance of learning to fundamental auditory perception. It is perhaps the case that there does indeed exist a central pitch processor which can be modified through learning, so that responses to certain patterns of stimuli can occur in a particular manner. In this way, an individual can learn to respond to musical stimuli, such as major triads, by attending to their fundamentals or roots. Triads with the same fundamental or root can then be treated in a musically similar way. Alternatively, individuals may learn to respond to triad inversions in a similar manner because their triadic components are merely octave displacements of one another.

Although it was demonstrated in the present work that inversions can be perceived as equivalent to one another, the component tones of these chordal positions differ with respect to octave of presentation and with respect to intervallic relationships with the other component tones, perceptual aspects which are exploited to create variety within musical compositions. It is noteworthy that musically-trained subjects automatically judged these three triadic positions as sounding similar to one another when given the ambiguous instruction to judge "similarity" of the chords. Furthermore, the circumstances under which they were required to perform the task were ambiguous, with no musical context presented beyond the triads themselves. It could not be determined on the basis of the present experiments, however, whether this perceived similarity was due to perception of a common root (or fundamental), or all three triadic tones.

This leads to the other way in which the studies of the present thesis provided support for music-theoretic relationships between chords built on different root-notes, and this also, was demonstrated for musically-experienced individuals in the absence of any more musical context than that of major triads. Experiments 1-5 all found support for an organization of triads built on different root-notes, an organization reflective of the theoretic Circle of Fifths. To the extent that two triads were considered musically related, as described by close proximity on the circle, musically-experienced subjects tended to judge them as sounding very similar to one another. In Experiment 5, where Shepard chords were employed to decrease the number of stimuli and to attenuate pitch-height and inversion factors, and when a specific instruction to judge "musicality" of the chords was given, an even clearer Circle-of-Fifths dimension was recovered. That such an organization could be found when only major triads were presented, is supportive of the theoretic proclamation that major triads are capable of instantiating key.

Apparently, those who have received formal musical education have acquired a heightened sensitivity to underlying musical structures. In the present thesis, these structures took the form of relationships between triads built on the same root-note (as demonstrated by inversion equivalence), and between triads built on different root-notes (as demonstrated by recovery of the Circle of Fifths). That such structures could be automatically accessed with a minimal amount of information (major triads and no other musical context) probably reflects the freeing-up of processing capacity for the myriad of other perceptual occurrences during musical processing. In this way, the apparent ability of a highly-skilled conductor to simultaneously attend to a number of highly complex occurrences in the music, may be reflective of training, which has allowed much of the processing to become predictable and automatic. This type of processing would be very useful, given the complexity and speed with which many of these musical functions must be accomplished.

The existence of a central pitch processor would aid in the organization and categorization of musical stimuli by decreasing the amount of processing needed to "make sense" of the music. For example, two triads built on different root-notes can possibly be of the same triad type and inversion, and may serve similar functions within the established key. An individual who possesses this information, and who also possesses the structures to make musical interpretations within the bounds of a particular music system, can then establish a number of expectations of likely occurrences in the music. Musically-trained individuals, for example, will likely be aware that most notes within a composition will be drawn from the established key, and that a certain percentage of them will be those considered highly stable within the key. Furthermore, these individuals will probably be aware that modulations usually occur between closely-related keys, and that the tonic usually occurs at the beginning and end of a musical selection. If such structures allow expectations to occur automatically, then this is an extremely useful mechanism in terms of allocation of resources to processing, considering the thousands of notes within a musical composition which must be patterned together in the form of melodic and harmonic organizations to create a comprehensive musical work.

Another important consideration is the difference between expert and novice musicians in terms of the number of structures and the elaborateness of the structures they possess. Musically-trained individuals in the present studies probably had a number of strategies available to them when making chordal judgements. These included judgements of the dimensions of pitch-height (absolute frequency of the highest notes of a chord), root-note (relationships between chords built on different root-notes), and inversion (relationships between chords built on the same root-note). The inexperienced individuals, by comparison, only demonstrated the use of pitch-height structures. If music-processing can be considered a problem-solving activity, such that each element within a composition is evaluated for its appropriateness to such musical aspects as the established key, rhythmic structure, tempo, texture, and mode, then musically-experienced individuals, who have had long periods of exposure and formal training with these structures, would be expected to have a much larger and more elaborate knowledge base to draw upon when making judgements. This would give those with a musical background an advantage in terms of consideration of relevant musical structures and solutions when faced with a decision concerning interpretation of a composition, performance, and practice.

Music is a highly structured domain, and these structures occur at many levels. It was shown in the present thesis that with more musical training comes the ability to access structures that exist for musical triads played with minimal musical context. Musically-untrained individuals were only able to access structures existing at a much more global processing level, and they judged the triads on the basis of their overall pitch-heights. To the investigator interested in the mechanisms underlying the acquisition of skills, and the cognitive changes incurred as a result of training, the present studies provided evidence that in the musical domain, processing becomes more highly structured and these structures become more accessible with degree of training.

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FOOTNOTES

[1]Close form refers to the presentation of all harmonic components within the span of an octave.

[2]Each major key is also related to a relative minor key (e.g., C major and A minor), in which the tonic of the relative minor occurs a minor third below the tonic of the major key. These keys also share the same key signature (i.e., same sharps and flats). Each minor key can also be thought of as related to a relative major key, in which the tonic of the relative major is a minor third above the tonic of the minor key. Regarding parallel major and minor keys (e.g., C major and C minor), these keys share the same tonic, but have different key signatures. These key signatures will differ in that the major key will have three sharps more than the minor key, while the minor key will have three flats more than the major key.

[3]A square matrix is one in which the number of rows is equal to the number of columns.

[4]Individual differences scaling can be applied to measures taken across different settings, conditions, or times of measurement, as well as different subjects.

[5]A symmetric matrix is one in which an entry for a particular cell, specified by a row number and column number, is equal to the entry of a cell in which the row number and cell number are juxtaposed. That is, $entry_{row,col} = entry_{col,row}$.

[6]The ordering described (first inversions, followed by root chords, then second inversions) is not as clear for the E- and A-major triads as for the Bb-major triads when this subordinate dimension is plotted against root-note. The described ordering is much clearer for the E- and A-major chords when presented with the pitch-height dimension, but this so-called secondary dimension was shown in the present thesis with the root-note dimension so that comparison could be made with the associated dominant dimension.

[7]Why instructions alone were not sufficient to alter a voice student's results from a predominantly pitch-height strategy to one of root-note in Experiment 1, when a change of instruction resulted in a change of strategy in the present experiment, could once again be due to the unreliable nature of results obtained by those whose main instrument is voice.