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Tonality and perception: Musical scales primed by excerpts from *The Well-Tempered Clavier* of J. S. Bach

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Summary. The psychological relevance of the musicians' concept of tonality was tested in the context of the music of J. S. Bach. Musically trained listeners were instructed to sing the musical scale that first came to mind immediately after hearing short excerpts from Preludes of J. S. Bach's *The Well-Tempered Clavier*. For each Prelude, the tonic (first note) and the mode (major or minor) of the scale produced were compared to the tonic and mode designated by Bach. Results indicated that listeners (1) often established the designated tonic and mode within the first four notes of the piece; (2) within the first four bars, often established tonalities different from that of the designated key, a tendency that increased by the eighth bar; and (3) reestablished the tonic in the last four bars. These observations validate, in general, music-theoretic assumptions about the listener's hearing of tonality, and raise issues regarding the salient relations that engage the cognitive structures underlying tonality perception.

Introduction

Tonality is a fundamental aspect of the structure of Western tonal music. Its importance is apparent in both scholarly writing and everyday discourse about musical scales, keys, and chord progressions (cf., Apel, 1969; Cuddy, Cohen, & Mewhort, 1981; Erickson, 1982; Hopkins, 1979; Krumhansl, 1983; Parncutt, 1989). Tonality entails the establishment of a reference tone, chord, or key. In addition, the quality or mode of the tonality, typically major or minor in the Western tonal system, is defined by the relations of the tones among themselves and to the tonic or reference tone. Whereas the reference and relations to it can be objectified in a music-theoretic analysis, it is generally assumed that the reference and particular relations of tones to that reference are also mentally represented by musically sophisticated listeners. Such an assumption, which may be regarded as a psychological hypothesis, appears in writings as early as Helmholtz (1954, p. 240). It also underlies the music-theoretical work of Schoenberg (1973) and Schenker (1954) to name only a few.

In the last decade, several psychologists have provided indirect evidence of the psychological establishment of tonality. They have demonstrated influences of objectively described cues to tonality on memory, recognition, and structural ratings of brief musical patterns or their component tones (e.g., Cuddy et al. 1981; Krumhansl, 1979, Experiments 2–4; Watkins, 1985). In these studies, the subjects were never explicitly asked to define the perceived key (i.e., to designate the tonic and the appropriate major or minor mode).[1]

Further advances in the specification of the mental representation of tonality followed the application of the probe-tone technique developed by Krumhansl and Shepard (1979). With this method, on each trial, a tonal context is provided through the presentation of a major or minor scale, triad or chord progression. Subsequently, subjects are presented with a probe tone, one of the 12 tones of a chromatic scale, and are asked to rate the degree to which it fits the preceeding tonal context. The resulting profile of ratings for the 12 chromatic tones reveals that the tones of the tonic triad are best suited to the context, followed by the

[1] Cohen (1977), however, did ask music theorists to indicate which of the 24 major or minor keys best accommodated each of 32 seven-note sequences designed to represent a wide range of tonal ambiguity. The theorists also provided music-structural analyses of the sequences. The number of different keys deemed appropriate by the theorists indicated the degree of key ambiguity. In a study reported by Cuddy, et al. (1981), the same sequences were also rated for degree of structure by listeners. Recent analysis of these data reveals a negative correlation (–.52) between the number of keys assigned as possibilities by the analysts and these structure ratings. Thus, sequences that had the greatest ambiguity of tonality according to music theory typically received lower ratings of perceived structure than did sequences with unambiguous tonality. A subsequent study of recognition of transposed seven-note sequences, containing three sequences from the earlier work, revealed a high correlation between structure rating and recognition (Cuddy et al. 1981) suggesting a linkage between key clarity and veridical mental representation of a melody.

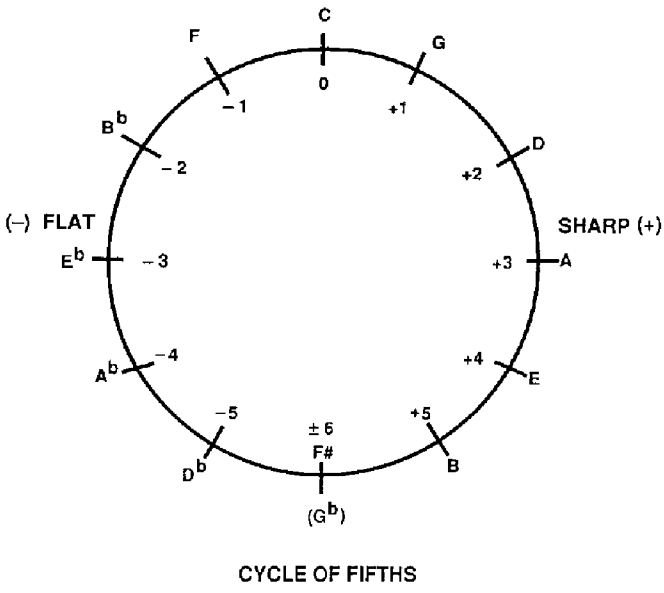

Fig. 1. Cycle of fifths. Clockwise direction increases number of sharps and counterclockwise direction increases number of flats.

remaining diatonic tones, and lastly the 5 non-diatonic tones. Because these experiments use musical prototypes such as the major scale, major triad, and chord cadences (e.g., Krumhansl & Kessler, 1982) to establish context, their generality to listening to real music is therefore hypothetical. It would be predicted that passages of real tonal music that establish tonality would establish a similar hierarchy. These predictions have been borne out by recent probe-tone tasks that used more realistic musical contexts (e.g., Schmuckler, 1989; Thompson, 1986).

Using the probe-tone technique, Krumhansl and Kessler (1982) precisely traced the developing and changing sense of key during the presentation of 10 sequences, each of nine chords in length, some of which contained changes in key. Profiles for the sequences were correlated with profiles for the intended key (major or minor). Profiles for the chords in isolation (major, minor, diminished) were correlated with profiles for the intended keys (major or minor). These correlations were compared, and the difference was interpreted as a sense of key arrived at by integrating over multiple chords. In all cases beyond the initial chord, the sense of key was stronger than that produced by the last-heard chord in isolation. This indicated a gradual development of the tonality with additional information in the piece. Because the sequences never began on the tonic chord, it is not possible to generalize this demonstration of developing tonality to music that begins with strong cues, such as tones of the major tonic triad. Nor is it clear how much information would be required for the perception of tonality of excerpts from real classical music, how much agreement there would be among listeners, and the extent to which agreement among listeners would confirm the key signature of the piece. Evidence from probe-tone studies that established a tonal hierarchy following the presentation of a scale or triad suggest that tonality could be established in classical music with only a few notes. Further evidence of the rapid establishment of tonality is provided by Cohen, Trehub, and Thorpe (1989) and Frankland and Cohen (1989), who showed effects of degree of tonality on memory with sequences of five tones.

In summary, musical discourse and psychological research imply that listening to music entails decisions about a tonic note to which other notes are related. Further explication of this process depends, in part, upon identifying the conditions under which listeners can assign key, both tonic and sets of tone relations, in the context of real music. Therefore an experiment was conducted to examine the listeners' ability to establish a tonic and major or minor mode. Questions of interest were: Are perceived tonics and mode agreed on by listeners? Do tonics and mode produced by listeners change throughout the course of a piece of music? Do these choices differ from tonic and mode designated by the composer or theorist?

Musical excerpts were drawn from *The Well-Tempered Clavier, Book 1* of J. S. Bach, a set of 24 Preludes and Fugues, composed in 1722, representing every major and minor key. The collection illustrated the practicability of the (then) new, equal-tempered tuning system. The title, *Well-Tempered*, refers to Bach's approval of this innovative temperament which made all musical keys equally accessible in contrast to previous tuning systems which confined performance to a few related keys (Terry, 1963). The present study used excerpts from Preludes 1–12 that represented tonalities from C to F inclusive, with even-numbered Preludes in the minor mode. In all cases, Preludes began on the tonic of the key signature and, in all but one case, within the first four note events they contained the appropriate mode-defining major or minor triad corresponding to Bach's designated key signature. The deviant example still included the appropriate third. There was therefore sufficient information for the extraction of tonality within the first few notes. Also, no non-diatonic notes, (notes outside the key) occurred in these short four-note excerpts.

Music-theoretic analysis of the Preludes reveals early establishment of the key specified by Bach often followed by key changes or modulations within the first eight bars, and sometimes sooner (e.g., Iliffe, 1965; Keller, 1976). Conforming to classical style (cf. Rosen, 1972) and modulation logic (Forte, 1962), changes are typically to related keys rather than to a random choice among the 24 possibilities. Keys most closely related share many tones and differ in few and can be derived in a variety of ways. For example, keys whose first or tonic notes are related by the musical intervals of the perfect fifth (7 semitones) differ in only one tone: the keys of C and G (related by the perfect fifth) share tones CDEGAB; whereas tone F belongs to the key of C and F# to the key of G. Twelve successive applications of the perfect fifth rule returns the original tonic note and produces the cycle of fifths shown in Figure 1. Here the difference between adjacent major keys or between adjacent minor keys is only one tone – moving clockwise one step adds one sharp; moving counterclockwise one step adds one flat. Major and minor scales can be related closely to each other in two ways: parallel, when the first note, the tonic, is the same for both scales, and relative, when the key signature is the same for both scales (cf. Krumhansl, 1990, pp. 32–34; Schoenberg, 1969,

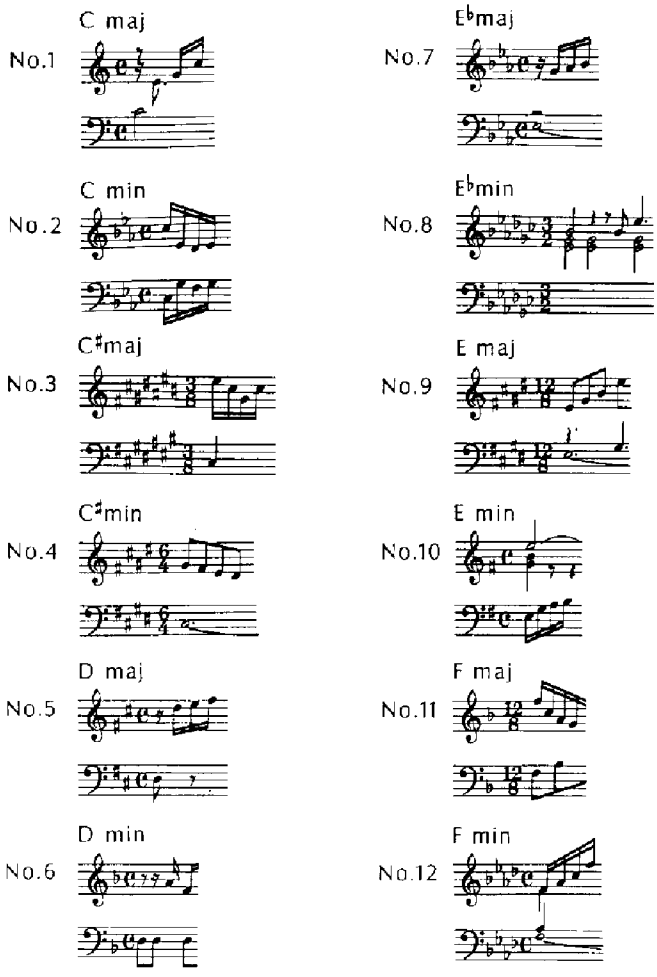

Fig. 2. First four note events of the first 12 Preludes of *The Well-Tempered Clavier* (used by permission)[2].

p. 20). In the latter case, the tonic of the major scale is one minor third above the tonic of the minor scale. Movement from a major scale to a relative minor is three steps clockwise on the cycle of fifths, and conversely movement from a minor scale to a relative major is three steps counterclockwise with respect to the cycle of fifths. Most of the key changes (e.g., as described by Iliffe, 1965) for the first 12 Preludes fall into this set of keys related to the tonic (i.e., movement to adjacent members on the cycle of fifths, or to parallel or relative major or minor keys).

Thompson and Cuddy (1989) studied listeners' ability to judge the distance (in numbers of cycles of fifths) and the direction of a modulation in short sequences adapted from Bach chorales. Such an approach assumes awareness of the concept of key change. It also assumes deliberate memory of the tonality of the beginning and ending of the examples and subsequent comparison processes. While revealing important information about the listener's awareness of changes in the representations of tonality, it avoids the issue of what information is specifically represented. In contrast, the present study seeks evidence of the listener's establishment of a specific tonality prevailing at particular locations in Bach's music.

The method of externalizing the listener's establishment of key used a response relatively natural to musically experienced listeners: that of singing the major or minor scale that came first to their attention following the presentation of a passage. At the very least, such a response depends upon the choice of a tonic and mode-defining major or minor third relative to the tonic. Agreement of tonics and modes among listeners for each of the various passages would imply the systematic representation of tonality based on musical relations in the passage. If listeners also agree with Bach's key signature, it would mean that the compositional rules of tonality as used by Bach reflect those internal to the listening experience. It is of course possible that listeners would require more information than that theoretically sufficient to establish tonality. However, if listeners in fact do infer sets of pitches from the outset, as would be expected within an information-processing framework (Cohen, 1977, 1978; Cohen et al. 1989; Garner, 1974), then tonality might be reasonably established after only a few notes had been heard. With modulation to new keys by the composer, systematic changes in the vocalized scale would be predicted. In accordance with the style of Bach's Preludes, such new scales would be keys near the original. It is also predicted that scales produced by listeners would reflect the return to the home key at the end of the composition.

Methods

The musical material was recorded from Decca Stereo Gold Label records, 1966, *The Well-Tempered Clavier*, perfored by Rosalyn Tureck on piano. The record was played on a Dual turntable through a high quality amplifier and recorded onto a Revox A700 tape deck at 3 ½ ips. Four excerpts were recorded from each Prelude: the first four sequential note events (i.e., the first four attack points of tones in sequence, including simultaneously presented tones in some cases; see Figure 2), the first four bars, first eight bars, and last four bars (see Figure 3). The mean durations of the excerpts were 1.4 s, 16.0 s, 32.0 s, and 19.4 s, respectively. The excerpts were spliced to form a test tape of 48 excerpts in all. The order of excerpts was random, with the restriction that excerpts of the same Prelude, tonic, or type (e.g., The first four bars) did not follow consecutively. The order was consistent for all subjects. Five practice segments were also recorded from Bach's French Suites.

Testing was carried out in a sound-attenuated room. Playback of the Revox tape-recorder was at a comfortable level via stereo headphones. Vocal productions were recorded through a Sony microphone on a Sony tape-recorder at 3 ½ ips.

Subjects were 18 musicians who had completed an average of two years in a university music-degree program and had achieved an average proficiency of the Grade X examination from the Royal Conservatory of Music of Toronto. The least experienced listeners had achieved the Grade VIII level while the most experienced had completed the ARCT Degree (Grade XI).

Pre-tests of 24 trials each were carried out for (a) vocal-pitch matching, (b) absolute-pitch naming, and (c) absolute-pitch vocal production. The stimuli for each of the tests were the 12 notes of the chromatic scale presented twice in random order as sine tones for tests (a) and (b) and in musical notation on file cards for test (c). The vocal productions were

[2] Segments from the *Study Score of the Well-Tempered Clavier*, Vol. I (No. 710), published by Belwin-Mills Publishing Corp., Melville, New York, the copyright owner, used by permission.

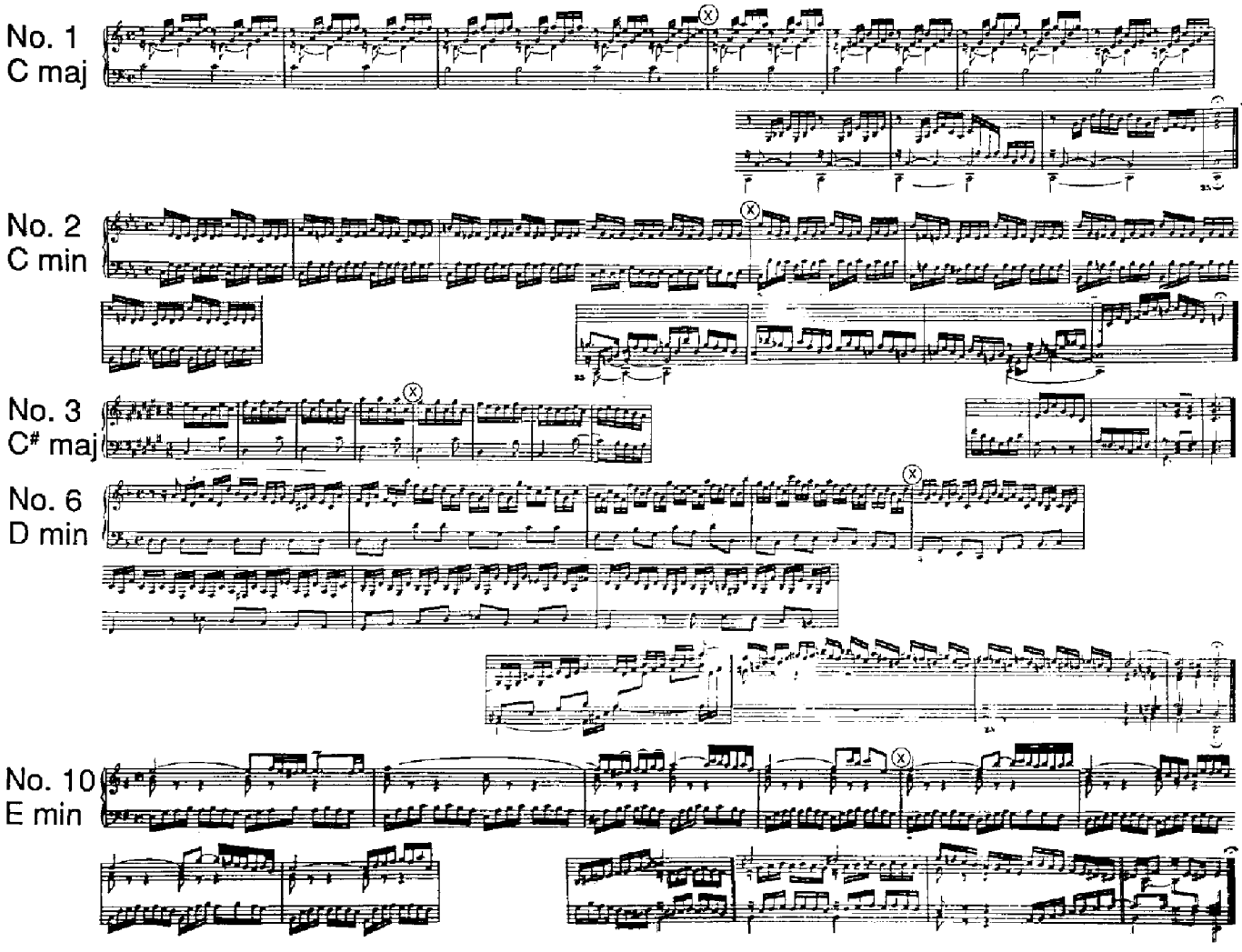

Fig. 3. Excerpts from selected Preludes of *The Well-Tempered Clavier*, illustrating longer segments: the first four bars (ending at the X), the first eight bars, and the last four bars.

tape-recorded for tests (a) and (c). Written responses were collected for test (b). Analyses revealed that all the listeners could vocally match pitch with an error less than one-half semitone, passing the criterion for participation in the study. There was greater variation in the ability to identify pure tones absolutely and produce them vocally from musical notation. Two subjects who performed consistently within one semitone (better than the other subjects) did not stand out in any other way in the experiment.

In the experiment, the subject was directed to sing the first musical scale that came to mind after hearing each excerpt. The entire test session was tape-recorded and lasted about half an hour.

[3] The assistant also provided a list of all responses which departed from the basic major- or minor-scale structure, including poor a ambiguous tuning, restarts, fumbles, influence from immediately preceding pieces, and other Greek modes. Approximately 5% of the produced scales were so indicated; and in cases of doubt for scoring tonic and third, the best guess was made. These anomalies did not seem to cluster around any particular variable in the experimental design or any particular excerpt. In addition, the decision to use only one judge in the present study was made on the basis of a previous study of sight-singing in which the independent responses of two judges were very highly correlated.

Results

Scales produced during the test session were transcribed by a music-degree graduate with good aural skills. He checked his transcriptions against a Moog synthesizer with C tuned to the C of the piano recording. The information in the transcription of the sung scales was then reduced to two symbols: which of 12 tonics and which of two (major or minor) modes, e.g., C major[3].

The data are shown in Figure 4. Each column represents a separate Prelude and each row refers to one of the four types of excerpt. Major Preludes appear in the top portion of the Figure and minor in the bottom portion of the Figure. For each excerpt, Bach's key is assigned 0, centred on the x-axis. All possible keys relative to Bach's key are ordered in terms of the cycle of fifths (see Fig. 1). Since keys can be reached through either clockwise or counter-clockwise direction, the maximum number of steps to a new key is 6. For example, a key that is 7 steps away in one direction is also reached by 5 steps in the other direction. Only the shortest distance is indicated. On the abscissae of Figure 4, keys that are sharper than the original (clockwise relative

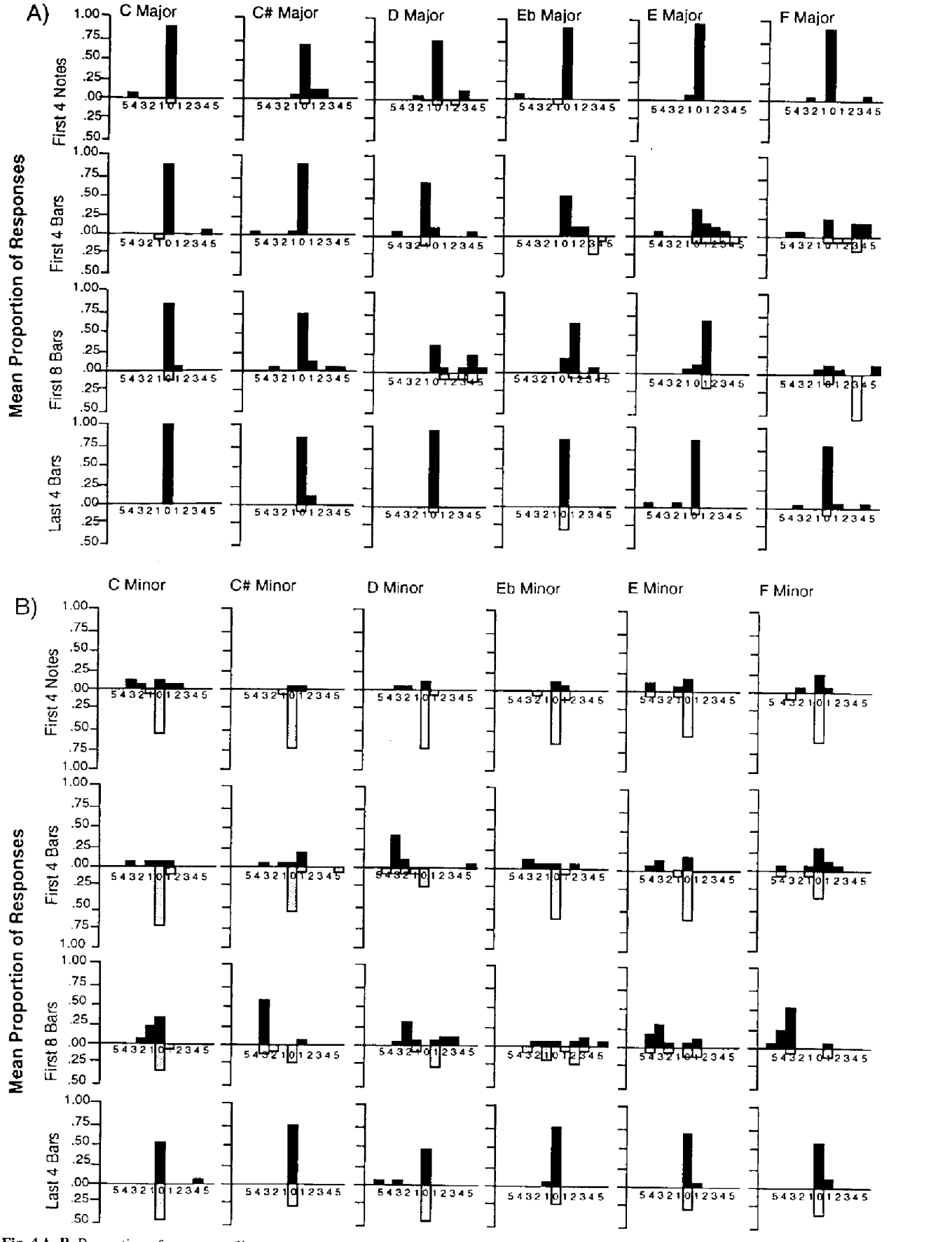

Fig. 4 A, B. Proportion of responses (listeners) of each tonic and mode (major/minor) to each of the major (**A**) and minor (**B**) excerpt types. The original tonic is set to 0. The other tonics are ordered by the cycle of fifths (see Figure 3), sharp on the right of 0 and flat on the left. Thus for the tonic D, "1" on the right refers to the tonic A and "1" on the left refers to the tonic G.

Table 1. For each of the 48 excerpts, proportion of responses: (a) correspondence with Bach's assigned tonic and mode; (b) absolute number of fifths from Bach's tonic; (c) signed number of fifths from Bach's tonic.

		First four notes			First four bars			First eight bars			Last four bars		
		a	b	c	a	b	c	a	b	c	a	b	c
Tonic	Mode												
C	Major	.89	.22	−.22	.89	.28	.28	.83	.06	.06	1.00	.00	.00
	Minor	.56	.67	−.33	.72	.33	−.11	.33	.39	−.28	.44	.22	.22
C#	Major	.67	.39	.28	.89	.33	−.33	.72	.67	.33	.83	.11	.11
	Minor	.83	.11	.00	.56	.72	.28	.22	2.17	−2.06	.28	.00	.00
D	Major	.72	.61	.39	.67	.56	.11	.33	2.17	2.06	.94	.00	.00
	Minor	.72	.33	−.22	.22	2.11	−1.78	.00	1.72	.06	.44	.44	−.44
Eb	Major	.89	.33	−.33	.50	1.22	1.22	.17	1.17	1.17	.83	.00	.00
	Minor	.67	.28	.06	.61	.67	−.33	.00	2.06	.61	.22	.06	−.06
E	Major	.94	.06	−.06	.33	1.33	.89	.11	.89	.78	.83	.39	.39
	Minor	.56	.78	−.78	.61	.67	−.67	.11	2.17	−1.72	.28	.06	.06
F	Major	.89	.33	.11	.22	2.22	1.44	.11	2.33	2.22	.78	.44	.11
	Minor	.61	.33	−.22	.33	.78	−.33	.00	3.00	−2.67	.33	.11	.11
Mean	Major	.83	.32	.03	.58	.99	.60	.38	1.22	1.10	.87	.16	−.03
	Minor	.66	.42	−.25	.51	.88	−.49	.11	1.92	−1.01	.33	.15	−.04

to Fig. 1) are represented to the right and those that are flatter (counterclockwise) are represented to the left. Thus, for Preludes in F, 0 represents the tonic of the key of F, 1 unit right represents the tonic of the key of C and 1 unit left represents the tonic of the key of B^b. For each Prelude, for each type of excerpt, the proportion of listeners that responded with a specific major scale (above baseline) or minor scale (below baseline) is shown.

If all subjects produced the key and mode that corresponded to Bach's key signature, a single, narrow bar representing the score of 1.00 mean proportion of responses would be found above (major) or below (minor) the 0 on the x-axis. Although such "perfect" performance is obtained only once (last four bars, C major), the most frequent response for all but one major Prelude excerpt corresponds to Bach's key signature and mode. For minor Preludes, by the eighth bar, the most frequent response is often a major key typically on the flat side of the original key (the relative major for Preludes in $C^\#$, E, and F, three steps left of tonic). For the first four notes, the mean proportion of responses exactly matching Bach's key and mode is higher for major (.83) than minor (.66) Preludes. From this relatively high correspondence after the first few notes of the piece, there is a decrease over the four- and eight-bar excerpts. At the end of the piece, the correspondence of tonics is very high, but the major mode is favoured for both major and minor Preludes.

Analysis of tonic and mode

For purposes of statistical comparison of the key (tonic and mode) assigned by Bach with the key that came to the subjects' mind when they were listening to the 48 excerpts, a response was assigned the value of 1 if it was the same as that chosen by Bach and the value 0 if either tonic or mode differed from Bach. The binary data from each of 18 subjects on each of 48 trials (4 types of excerpt × 2 modes × 6 tonics) were entered into an analysis of variance with three within-subjects factors of type of excerpt having four levels, mode having two levels, and tonic having six levels. The entries under "a" in Table 1 show, for each excerpt, the proportion of responses that exactly matched Bach's assigned key for the Prelude from which the excerpt was drawn. For example, for the opening four-note excerpt from the C major Prelude, .89 proportion of responses were C major, whereas for the C minor Prelude, the proportion of C minor responses was .56. Greater exact correspondence was associated with major (.67) over minor (.40) modes, $F(1,17) = 48.7$, $p < .01$. Flatter distributions of responses for the minor modes, shown in Figure 4, suggest that the tonic and mode of the minor Preludes is more difficult to discern. In addition, there may be a bias to sing major modes. Greater exact correspondence was found for opening four-note excerpts (.75) as compared to first four bars (.55), first eight bars (.25) and last four bars (.60). The effect of excerpt type was significant, $F(3,51) = 40.2$, $p < .01$. While, in general, perfect correspondence with Bach's key was higher for major than for minor modes, this difference was not large for the four-bar excerpts (.58 vs. .51), but was extremely large for the final four bars (.88 vs. .33), the latter resulting from the production of scales in the parallel major of the original minor key. The interaction of type of excerpt and mode was significant, $F(3,51) = 9.6$, $p < .01$.

Keys closer to the chroma of C (i.e., in terms of number of semitones, e.g., $C^\#$ as opposed to F) led to higher correspondence with Bach's key, $F(5,85) = 12.3$, $p < .01$. It is

unclear why proximity to the pitch of C would influence correspondence, although a more complex style may characterize Preludes in keys further from C. For example, Keller (1976, p. 27), commenting on the richness of the 24 Preludes, describes major Preludes in C, C#, and D and the minor Prelude in C# as being "in the older style," "made up of scale passages and broken harmonies," whereas he describes the major Prelude in F as a two-part invention, E major as a three-part invention, and minor Preludes in C#, D#, E, and F as arioso pieces.

Although typically the opening notes led to higher correspondence with Bach's key than did four-bar and eight-bar excerpts, there were exceptions. For example, the Preludes in C do not show higher correspondence with Bach's key in the opening four notes. Such events account for the significant interaction between type of excerpt and tonic, $F(15,255) = 4.2$, $p < .01$. As well, individual excerpts deviated from the typical pattern and accounted for the significant interaction between excerpt, mode, and tonic, $F(15,255) = 33.04$, $p < .01$. For example, the "correct" scores for the C and C# major eight-bar excerpts are relatively high compared to those of the remaining 10 Preludes.

Analysis of tonics by the cycle of fifths

For a comparison of the relation of the sung tonics to the originally specified tonic of the key signature, the tonic of each scale was scored for degree of remoteness from the original tonic in terms of the cycle of fifths ignoring mode. The original tonic was set to 0 and sung tonics were assigned signed integer values depending upon how many steps they were removed from the original key. For example, if the tonic was D and the sung scale G, the value of the G scale would be –1, since G is one step on the flat side of D in the circle of fifths. For a major key (e.g., D), moving to the relative minor, the scale (B) would be +3; for minor going to relative major, –3.

The integers were entered into the analysis of variance for each subject for each of 48 trials. This analysis is potentially complicated by the fact that the largest step, of 6, is equally distant from the original tonic on sharp and flat sides and can be associated with positive or negative value. There were, however, no such responses in the data. The signed integer information may be misleading unless complemented by information about absolute deviation. For example, if one half of the subjects produced a scale 1 unit flat and the other half produced a scale 1 unit sharp, the resultant signed value would be 0, a result equivalent to that derived when all subjects gave the "correct" scale. The absolute value of the deviation provides information about the total size of all deviations from the original key. Absolute values were therefore analysed also. Both analyses again considered the three within-subjects factors of type of excerpt, mode, and tonic. F_{ab} and F_s will refer to F ratios from the results of the analysis of absolute and signed values respectively.

Entries under "b" and "c" of Table 1 represent the mean number of absolute and signed steps from Bach's tonic respectively. The mean absolute value (see bottom of table) increases from less than 0.5 units for the shortest excerpts to more than 1.0 units for eight-bar major excerpts and closer to 2.0 units for minor excerpts. A similar trend appears for the signed integers (column c) which are always lower (in absolute terms) than the corresponding unsigned values (column b) as a result of cancellation of judgments of opposite sign. The mean signed deviation for major and minor Preludes of four and eight bars are in opposite directions, although close in absolute size. This is consistent with the view that major keys typically modulate clockwise and minor counterclockwise (Hopkins, 1979, pp. 44–45) and also follows from the fact that movement from the major to the relative minor would be positive, and that from the minor to the relative major negative. Such movement was prevalent for these excerpt types. In fact, for C#, D, E, and F minor Preludes, the most frequently perceived key change was to the relative major (see Figure 4). Modulations in opposite directions for these excerpt types account for the absence of a significant main effect of excerpt type for the signed values (means collapsed over major and minor excerpts fall within the range of –.22 to .11 units) and only the analysis of signed values revealed a main effect of mode, $F_s(1,17) = 165.1$, $p < .001$. Type of excerpt, $F_{ab}(3,51) = 62.6$, (but $F_s = 1.2$, $p > .20$), type of excerpt by mode, $F_{ab}(3,51) = 6.1$; $F_s = 3.4$, tonic, $F_{ab}(5,85) = 12.7$; $F_s = 3.4$, and type of excerpt by tonic, $F_{ab}(2,255) = 5.7$; $F_s = 5.9$, were all significant at the .01 level. Again, differences for individual passages are apparent and may have accounted for the main and interacting effects with tonic. For example, for the shortest excerpt for E major there is almost no deviation (.06), while for D major there is a mean deviation greater than .5. Referring to the notation in Figure 1, it can be seen that the perfect fifth of the major triad is not present in the D major Prelude, unlike all other Preludes. This suggests that the theoretically sufficient information of the interval of the major third may not be adequate on its own to establish the tonality. The triple interaction of type of excerpt, mode, and tonic, was significant for both absolute and signed values, $F_{ab}(15,255) = 4.9$, $p < .01$; $F_s = 4.6$, $p < .01$, again attributable to individual excerpts.

Discussion

The experiment indicates that the information in the first four notes of the Preludes is generally sufficient for the musically trained listener to establish tonality – a tonic and mode. This ability is consistent with an information-theoretic assumption that subjects infer sets of pitches from the outset of a musical composition. The results also show that the perceived tonality can change within four bars and is more likely to change within eight bars, and, finally, that the listener can find the original tonic again by the end of the piece. The consensus among listeners and with Bach indicates shared knowledge of tonality cues, at least among listeners familiar with classical Western tonal music.

In order to account for occasional lack of correspondence with Bach's key for shortest segments, it can be hypothesized that (1) salient information such as thirds and triads may vary in ease of abstraction; for example, Cuddy and Cohen (1976) showed that ascending or descending

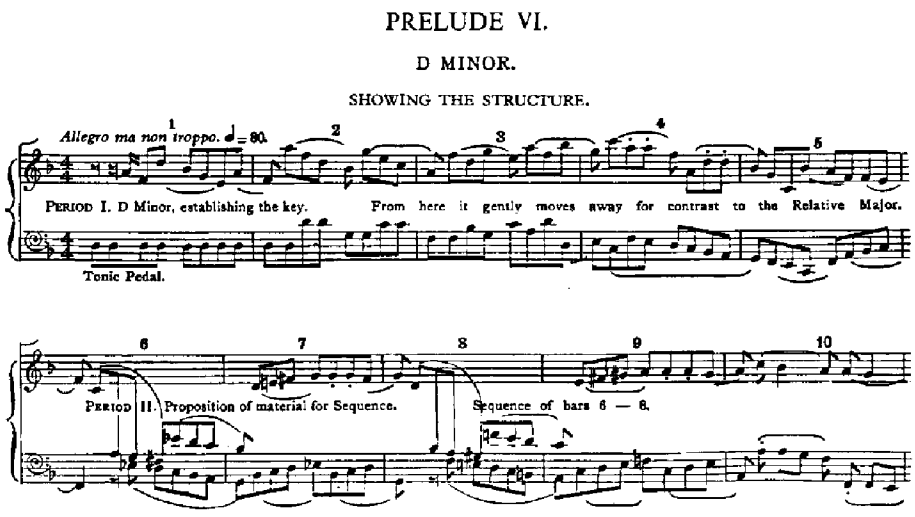

Fig. 5. Analysis of Prelude 6 in D Minor by Frederick Iliffe, reproduced from *Analysis of Bach's 48 Preludes and Fugues (book 1)* by permission of Novello & Co. Ltd.

major triads are more accurately recognized than those with a more complex contour (the C♯ major four-note excerpt is the only short major Prelude excerpt with an up-down contour and led to the lowest correspondence with Bach's designated key); (2) there may be competing cues – this might be truer for longer passages, as it is noted that there are *no* accidentals or non-key notes in the first four note-events; (3) even with sufficient evidence, the listener is not necessarily an ideal information processor; (4) individuals may differ in strategy; for example, Frankland and Cohen (1990) noted subtle differences in probe-tone profiles among musically trained listeners (see also, Umemoto, 1990). These factors may account for variability of response to the longer excerpts as well. The choice of scales depends upon both the relations among tones in the excerpt and the propensities in the mind of the listener for abstracting those relations and for providing a context for them. Differences either in veridicality of the representation of these relations or in the particular criteria for judging the tonic and mode presumably account for the varying responses among individuals.

Examination of the responses of all listeners for individual Preludes sometimes reveals more than one favoured scale, especially as the Prelude proceeds. The multiplicity of choices can be accommodated by certain music-theoretical notions. For example, the tonic and the set of keys related to it, as described earlier (e.g., for a major scale the two adjacent majors and the parallel and relative minor), accounted for the majority of scales produced for each excerpt type: .92, .76, and .81 for the major Prelude initial excerpts of increasing length; .87, .79, and .56 for the corresponding minor Preludes; and .96 and .99 for major and minor endings respectively. In this regard, it is useful to consider in detail a Prelude that led to a variety of scales for the longer excerpts.

Prelude 6 in D minor (see Figure 3) presents the tonic minor triad in the first four attack points: two repeated tonics followed by the fifth and the minor third, accompanied by an additional presentation of the tonic. Over 80% of the subjects chose D as tonic and over 70% chose both D and the minor mode. Iliffe's (1965) description, partially quoted in Figure 5, indicates an initial establishment of the key for one and a half bars and, in his words, "from here it gently moves away for contrast to the Relative Major." The so-called "gentle" modulation to the relative major, to F major in this case, is reflected in the scales sung by the subjects at the end of four bars. Here the most frequent response is F major (40% of responses), followed by D minor (accounting for 20% of responses) and by C major (about 10% of responses). Each of the different choices seems both reasonable (in the way that A♭ major, for example, would not) and non-random, and may result from idiosyncratic patterns of attention, (e.g., retrospective, local, or anticipatory) or from various levels of processing (cf. Lockhart & Craik, 1990). The variance of the results complements, to some extent, the music theorist's description, which includes these possibilities (i.e., F is the relative major, D is the original minor key, and C is the dominant of F). Iliffe remarks (p. 18) that bars 6–8 modulate to G minor, followed by a modulation to A minor. The scales chosen by the subjects again reflect the music analysis. First of all, no listener chose D minor as the key or D as tonic. Tonality, both perceptually and theoretically, then, has changed. The most frequent responses are A minor and C major. The eighth bar ends on an E dominant seventh chord of A. Because C rather than C♯ appears in the bass line, A minor, as opposed to A major, could come to mind. C major, the relative major of A minor, would also be possible. In addition, C is 1 unit from the prevailing G minor. Nevertheless, C major is not mentioned in this particular theoretical description, suggesting that a music analysis may be incomplete in predicting what listeners hear.

Music analysis does account for the preponderance of major scales produced at the end of the minor Preludes. It was the convention to end minor pieces on the major chord (cf. Keller, 1976, p. 37). Listeners discerned the tonic reliably but on many occasions chose the major mode. Their choice agrees with the music-theoretic rule that the "last wins out" (Schoenberg, 1973). It was suggested by Helmholtz that Bach, like the composers before him, had used the major chord in a minor piece to mark the tonic better. In other words, the major triad more clearly defines the tonic than does the minor.

"The medieval composers down to Sebastian Bach used for their closing chords either exclusively major chords, or doubtful chords without the Third. . . Of course other considerations, besides the degree of consonance, have great weight in determining the final chord, such as the desire to make the prevailing tonic or key-note with distinctness, for which purpose the major chord is decidedly superior." (Helmholtz, 1954, p. 217).

Hence, in addition to listeners' bias to sing major modes, the minor tonalities may be more difficult to process. This is also in accord with the evidence of Roberts and Shaw (1984) that, in a same-different recognition paradigm, the major triad is more accurately identified on the same trials than the minor.

The systematic differences in the distribution of scales sung by listeners in the present study also converges with the evidence of Thompson and Cuddy (1989) for the detection of modulation in Bach chorales. Since they considered only major keys, we limit discussion to major Preludes. In their study, each stimulus sequence began on the tonic note of the chorale and was followed by a sequence of four other notes from the tonic triad and finally by eight chords from the chorale. The sequences can thus be compared to the four-bar excerpts in the present study which also began on the tonic note, followed by notes of the tonic chord, and completed by additional material that either modulated or did not. In their study, when the key did not change and ended on the original tonic chord, listeners correctly claimed that the key had not changed in roughly 90% of the cases. In the present study, in the C major Prelude, subjects produced the original key on 80% of the occasions, a figure close to that reported by Thompson and Cuddy (1989). When mode, but not key signature, changed (as in the C# Prelude) performance declined, as did that reported by Thompson and Cuddy (1989) for chorales that changed mode, but not key signature. For key changes to the dominant as in D and E major Preludes, subjects produced a key change on average about 50% of the occasions (33% for D major and 67% for E major). For Thompson and Cuddy (1989), subjects detected such a change correctly on only one-third of the occasions. As is shown by the differences in the present results for D and E major, the individual structure of the Prelude may determine whether a modulation will be more or less detectable.

It has already been mentioned that none of the opening four-note sequences contained non-diatonic tones. In addition, neither the sixth nor the seventh note of the scale ever appeared, thus emphasizing the first tetrachord (the first four notes) of the scale. The absence of the seventh note is interesting, given that it belongs to the rare, highly informative, tritone interval of the diatonic scale. Brown (1988) and Butler and Brown (1984) have emphasized the significance of rare intervals for establishing tonality unambiguously. Nevertheless, it appears that for real listening to music in the Baroque style, certain arrangements of the major tonic triad and the second note of the scale are sufficient for quickly establishing the key.

Finally, the external validity of the present data base is in part supported by recent work of Krumhansl (1990, pp. 83–86) in which a musical key-finding algorithm of Krumhansl and Schmuckler was applied to the shortest excerpts used in the present study. The algorithm computes the relative durations of each of the 12 chromatic tones comprising an excerpt and compares this distribution to that of the probe-tone profile for each key derived by Krumhansl and Kessler (1982, Experiment 1). Correspondence between the key selected by the algorithm and by the subjects in the present study is especially high for the major Preludes. The tendency for the algorithm to find Bach's key more often than the listeners did for minor Preludes is in keeping with the view that for human listeners, tonality cues are more difficult to discern in a minor key. For this reason, Bach may have provided even stronger cues in the minor mode; this would account for the fact that the key-finding algorithm on average finds Bach's key more often on the minor than major modes, the reverse of the human-performance data in the present study.

In conclusion, the present study adds to the growing body of evidence that musicologists' intuitions about tonality correspond to empirically demonstrated cognitive operations. The data that showed both the establishment of tonality in a very few notes and the subsequent changes of tonality in later portions of the music substantiate certain premises of music theory, but may also call for greater elaboration.

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