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CHORDAL-TONE DOUBLING AND THE ENHANCEMENT OF KEY PERCEPTION

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The choice of doubled pitches in the spelling of triads in Western four-part harmony is shown to correlate strongly with Krumhansl's tonal hierarchy. A study of chord spellings in 50 chorale harmonizations by J.S. Bach shows that Bach doubles those pitches that are predicted to most enhance the perception of the prevailing key. Krumhansl's tonal hierarchy accounts for a number of traditional music-pedagogical recommendations, including why composers avoid doubling the leading tone.

In Western harmony consisting of four or more parts, composers have some liberty in choosing which tone of a triad may be doubled—that is, which of three pitch-classes may be duplicated. Over the centuries, music theorists have proposed a number of recommendations concerning what tones are best doubled in the spelling of chords. In general, the doubling of the root of the chord is preferred, although theorists have identified many exceptions to this principle. Horwood (1948), for example, recommends doubling the root in the *I*, *IV*, and *V* chords, whereas either the root or third may be doubled in the *ii*, *iii*, and *vi* chords. Benjamin, Horvit, and Nelson (1992) identify a hierarchy of preferred doublings: "Scale-degrees 1, 4, and 5 are most often doubled; 2, 3, and 6, less so; and the leading tone, very rarely." Music theorists are unanimous in recommending against doubling the seventh scale degree or leading tone. In addition, theorists advise against doubling chromatically altered tones—that is, tones outside of the prevailing key (e.g., Benward & White, 1989, p.36; Cooper, 1981, p.156). Ottman (1989) recommends doubling of the tonic, dominant, and subdominant pitches and implies that the purpose of doubling is to enhance the "key stability" (p.91).

There are many possible factors that may influence the doubling of chordal tones. Perhaps the most important constraints arise from the rules of voice-leading. The proximity of successive pitches within each voice, plus prohibitions against parallel fifths and octaves, exposed octaves, part-crossing, etc., limit the composer's choice in the doubling of chordal tones. Voice-leading concerns alone may account for the injunction against doubling the leading tone since, in many harmonic progressions, movement to the nearest scale tone (tonic) will result in parallel octaves. However, the recommendations offered by theorists concerning the doubling of chordal tones all assume prior compliance with the rules of voice-leading. Even if proper

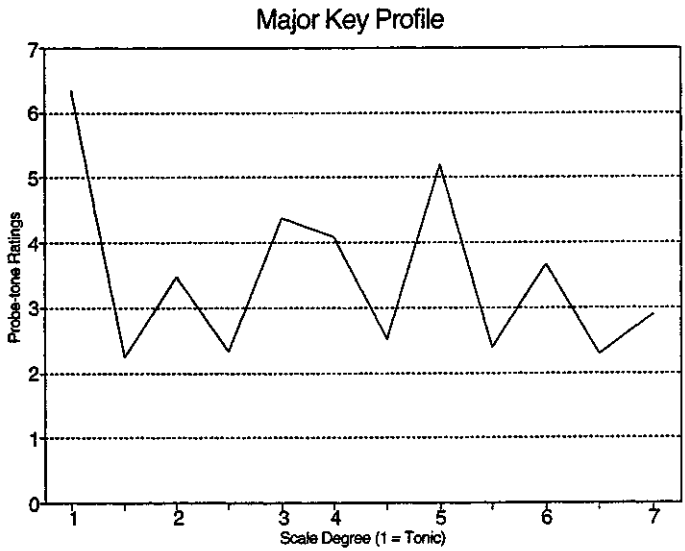
voice-leading is followed (for example) in a *iii-vi* progression, many theorists consider it undesirable to double the leading tone in the *iii* chord.

Note that most recommendations regarding chordal-tone-doubling explicitly link the spelling of a chord to the key context in which the chord appears. For example, apart from doubling the chord root, the best pitch to double for an E minor chord in the key of C major is thought to be the third (dominant pitch G); the worst pitch to double is the fifth (leading tone B). However, if the E minor chord is in the key context of B minor, then the best pitch to double (after the root) is thought to be the fifth (tonic pitch B).

The fact that these traditional heuristics link chord spellings to *key context* suggests that there is a relationship between the perception of key and chord spellings. At least three possibilities may be entertained. Either the key context somehow enhances the perception of a chord spelled according to pedagogical recommendations, or the recommended chord spellings somehow enhance the perception of the prevailing key, or the agreement of chord spellings and key context furthers some other (unknown) music goal.

Krumhansl (1990) has described a structural view of tonality in which key perceptions are correlated with the prevalence of various pitch-classes. Specifically, Krumhansl and Kessler (1982) played key-defining stimuli consisting of either single triads, or one of three chord progressions in either major or minor keys (IV-V-I, vi-V-I, or ii-V-I). Following each stimulus, one of the 12 pitch chromas was presented and listeners were asked to rate how well each of these probe tones fit with the preceding music context. Figures 1a and 1b show the resulting key profiles for diatonic major and minor key contexts. A four-level response pattern or "tonal hierarchy" is evident in which the highest rated pitch is the tonic, followed by the dominant and mediant tones, followed by the other diatonic pitches, followed by the nonscale tones.

Although other factors are known to influence the perception of tonality, Krumhansl's tonal hierarchy is strongly implicated in tonality-related perceptual phenomena. In the first instance, correlations between the major and minor key profiles and the distribution of pitch-classes within tonal music works are consistently high (average $r = 0.88$). Experiments have shown that listeners in both Western and non-Western cultures are highly sensitive to the frequency of occurrence of pitches in music genres (Castellano, Bharucha, & Krumhansl, 1984; Kessler, Hansen, & Shepard, 1984; Krumhansl, 1990). In addition, studies have traced the developmental acquisition of the tonal hierarchy among Western children (Krumhansl & Keil, 1982; Speer & Adams, 1985; Cuddy and Badertscher, 1987). These results imply that culturally-determined pitch distributions act as schemas by which tonal bearings are formed and maintained. A host of studies are consistent with this view. Studies of tonal memory have shown that listeners better recall those pitch-classes having the highest probe-tone ratings, that listeners are more apt to confuse pitch-classes having high probe-tone ratings, and that listeners are more apt to confuse lower-rated pitch-classes with higher-rated pitch-classes (but not *vice versa*). The tonal hierarchy accounts for various as-



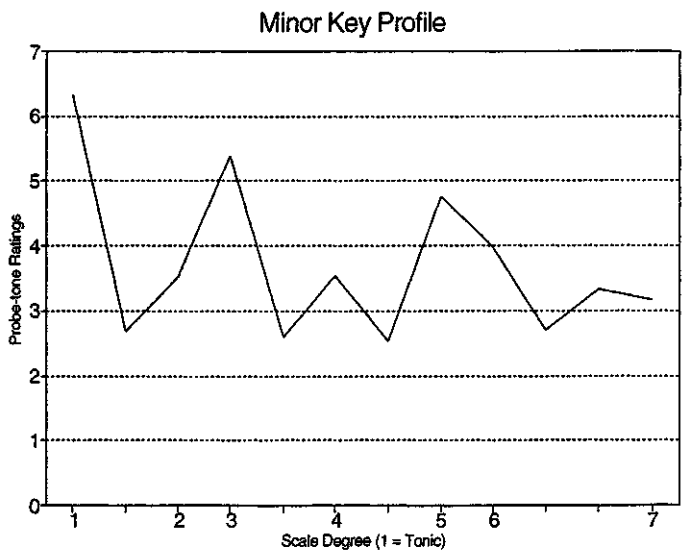


Figure 1. Average probe-tone ratings of key stability for scale-degrees in major and minor key defining contexts. From Krumhansl and Kessler (1982).

pects of the perception of bitonality (Krumhansl, 1990) and also accounts for the "contra-tonal" perceptual experience of listeners when listening to atonal music (Huron, 1992). In addition, by cross-correlating the distributions for different keys Krumhansl has shown that it is possible to generate a spatial representation of interkey distances that replicates the circle of fifths. Krumhansl has also applied this approach to replicate the more complex theoretical representations of tonality perceptions found in North Indian music (Krumhansl, 1990).

According to Krumhansl's tonal hierarchy, doubling the tonic and dominant pitches in Western tonal music might be expected to enhance the prevailing key perception, whereas doubling the leading tone or chromatically altered pitches might be expected to undermine the prevailing key perception. In short, there is a notable resemblance between traditional recommendations for chordal-tone doubling and Krumhansl's tonal hierarchy.

Of course other factors are known to influence the perception of tonality. In particular, key perceptions are known to be influenced by the temporal ordering of pitches (Brown, 1988; Butler, 1989; Huron & Parncutt, in press). *A priori,* there is no reason to believe that conformity to the tonal hierarchy would be *necessary* to evoke or promote a given key perception. However, the existing research implies that the tonal hierarchy may be *sufficient* to establish or maintain a given tonal center. Having addressed the constraints imposed by voice-leading, if some choice in the doubling of chordal tones remains for a composer, why not double those pitches that might be expected to contribute most to the key perception?

Hypotheses

If it is proposed that Krumhansl's tonal hierarchy accounts for practices in the doubling of chordal tones, then a number of empirical predictions may be made, and tested. First, the pitch-class distribution of doubled-tones ought to show a strong positive correlation with the appropriate tonic major or minor key profile. Second, the distribution of doubled-tones ought to complement the distribution of non-doubled tones so that the aggregate distribution correlates more strongly with the pertinent key profile. As a corollary, removing doubled-tones from music scores ought to weaken the tonic key correlations. A third prediction arising from Krumhansl's tonal hierarchy suggests that if we were to change the chord spellings so that *different* pitch-classes are doubled, then a marked erosion of tonic key correlations should occur. Finally, a notable discrepancy exists between Krumhansl's key profiles and traditional theoretical recommendations regarding the relative importance of the mediant and subdominant pitches. Theorists have traditionally recommended doubling the subdominant pitch, but have remained silent concerning the doubling of the mediant pitch. By contrast, Krumhansl's key profiles suggest that the mediant may have a greater key-enhancing effect than is the case for the subdominant. Thus a fourth hypothesis would predict that doubling of the mediant would be more common than doubling of the subdominant.

In order to test these predictions, a study of chordal tone doubling was carried out for a sample of four-part harmonic writing. If Krumhansl's tonal hierarchy is an adequate index of tonality, and if the establishment of key is an important factor in the choice of doubled tones, then the above predictions should be borne out.

Method

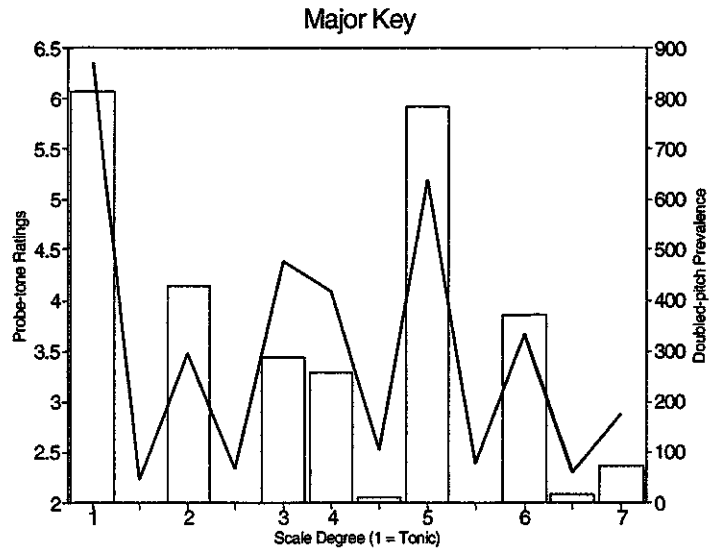
Music Sample

In selecting an appropriate sample of music for study, several criteria need to be considered. The sampled music should contain more than three concurrent parts and be predominantly chordal in nature. In addition, each sampled work must remain in a single well-defined key with few modulations or tonicizations. Since longer works nearly always modulate, an appropriate music sample would focus on very short works. To this end, a sample was taken consisting of 50 of the 371 chorale harmonizations by Johann Sebastian Bach (assembled by Riemenschneider, 1941). Even in these works, modulations and tonicizations are common. Modulations occur when chord progressions are functionally related to a new tonic. In minor keys, Bach frequently harmonizes entire phrases in the relative major key-area. Tonicizations arise due to the momentary use of chromatically-altered chords in a *V-of* or *vii-of* function. In particular, it is common for Bach to tonicize the dominant and submediant tones. In general, the tonal centers for chorales in nominally minor keys appear to wander more than is the case for chorales in major keys. Hence, the sampling procedure was purposely biased towards the selection of works in major keys. In total, 44 of the 50 selected harmonizations (88%) were in major keys. By contrast, of the entire collection of 371 chorales, only 52% are in major keys.

Procedure and Initial Results

Each work was encoded in a computer database. The encoded data were then subjected to an error detection regime (Huron, 1988) and estimates made of the data reliability of the encoded score data. Pitch and duration errors were estimated to be on the order of 0.5%.

As an initial test, all of the doubled chordal tones were extracted from all works in the sample and tabulated according to scale degree. "Doubled tones" were defined as any pitch-class that appears more than once for any given vertical sonority. Two aggregate distributions were tabulated, one each for works in major and minor keys (see Figure 2). These distributions of doubled-tones were then compared with the major and minor key profiles determined by Krumhansl and Kessler (1982). In the case of the minor key profile, the tonic key correlation for doubled-tones in the six chorales written in minor keys was determined to be $r = 0.89$ ($df = 11$; $p < 0.001$). In the case of the 44 chorales written in major keys, the tonic (major) key correlation for doubled-tones was determined to be $r = 0.94$ ($df = 11$; $p < 0.0005$). Although these correlations are large, by themselves they do not demonstrate that doubled tones are chosen so as to enhance the perception of key—



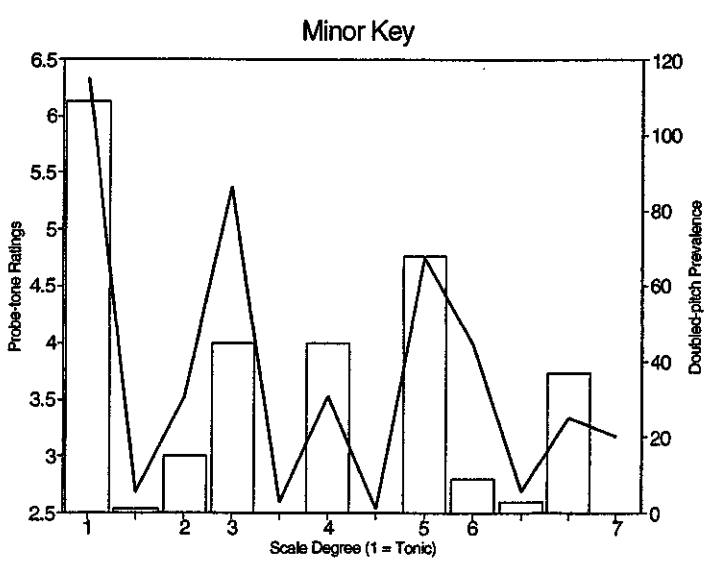


Figure 2. Comparison of Krumhansl and Kessler key profiles (solid lines) with prevalence of doubled-tones in 50 chorale harmonizations by J.S. Bach (bars). Coefficients of correlation: r = +0.94 (major key), r = +0.89 (minor key).

in accordance with Krumhansl's tonal hierarchy. It is already known that distributions of pitches in tonal music show large positive correlations with Krumhansl and Kessler's tonic key profiles. A more pertinent test is whether the correlations for the doubled-tones are significantly higher than the corresponding correlations for the complete works. Moreover, rather than amalgamating all of the works together, a stronger statistical test would examine the effect of doubled tones within each individual work.

To this end, three conditions were defined in line with the hypotheses outlined earlier. Condition 1 consisted of the original unmodified scores for the 50 sampled works. Condition 2 consisted of the original scores, excluding the doubled pitches. For example, where an original sonority might consist of the pitches C^2, G^3, E^4, C^5, the Condition 2 score would omit C^5. In this condition, the number of pitches in each score was reduced by between 23 and 28%. In Condition 3, scores were modified so that doubled-pitches were eliminated, and another pitch in the sonority doubled instead. For example, an original sonority consisting of the pitches C^2, G^3, E^4, C^5, might be rendered as C^2, G^3, E^4, G^4, or as C^2, G^3, E^4, E^5. In other words, one of the undoubled pitches was randomly selected and doubled in place of the original doubling. For convenience, we will refer to these three conditions as the "actual," "excluded-doublings," and "modified-doublings" conditions respectively.

The key of each work was determined *a priori* by inspection of the score. For each of the 3 conditions, key correlations were calculated for the *a priori* key for each of the 50 works using the appropriate major or minor key profile. Note that Krumhansl's key profiles are insensitive to pitch height; hence, in Condition 3 (where random tones are doubled) the pitch height of the newly doubled chordal-tone is inconsequential.

Results

The investigative results are shown in Table 1. In the case of the actual music (Condition 1), the average key correlations for the correct key was determined to be 0.895. In the case of the excluded-doublings condition (Condition 2), the average key correlation dropped to 0.860. Compared with the actual music (Condition 1), 48 of the 50 chorales displayed lower key correlations in the excluded-doublings condition. This reduction is highly significant ($\chi^2 = 42.32$; $df = 1$; $p<0.0001$) and is consistent with the prediction that doubled-tones play a greater key-defining role than other tones from the same work.

When doubled-tones were eliminated, and one of the other tones in the sonority was (randomly) doubled (modified-doublings condition), the average key correlation dropped again to 0.824. Compared with the excluded-doublings condition (Condition 2), 47 of the 50 chorales displayed lower key correlations in the modified-doublings condition; again this is a highly significant reduction ($\chi^2 = 38.72$; $df = 1$; $p<0.0001$). This result is consistent with the prediction that, of the possible tones that may be doubled, the

Table 1

Correlations Results

Chorale Number	Condition 1 Actual	Condition 2 Excluded-Doublings	Condition 3 Modified-Doublings	Chorale Number	Condition 1 Actual	Condition 2 Excluded-Doublings	Condition 3 Modified-Doublings
9	0.783	0.761	0.709	187	0.798	0.805	0.756
19	0.715	0.658	0.646	200	0.781	0.776	0.745
24	0.966	0.932	0.898	201	0.887	0.863	0.835
28	0.967	0.928	0.840	217	0.795	0.769	0.736
30	0.966	0.926	0.886	223	0.901	0.855	0.807
32	0.944	0.905	0.901	224	0.916	0.908	0.845
46	0.910	0.892	0.841	248	0.906	0.859	0.811
48	0.929	0.844	0.767	255	0.951	0.913	0.916
54	0.917	0.876	0.851	258	0.967	0.951	0.918
68	0.922	0.872	0.839	268	0.939	0.887	0.885
69	0.878	0.802	0.775	272	0.794	0.793	0.767
88	0.850	0.815	0.746	273	0.845	0.828	0.814
98	0.878	0.894	0.889	276	0.852	0.783	0.705
101	0.957	0.897	0.866	282	0.913	0.888	0.853
110	0.862	0.834	0.784	290	0.839	0.804	0.778
117	0.869	0.832	0.763	299	0.943	0.908	0.892
124	0.802	0.742	0.697	303	0.929	0.868	0.879
136	0.866	0.847	0.845	306	0.886	0.866	0.852
153	0.978	0.944	0.907	323	0.908	0.863	0.840
157	0.910	0.865	0.809	328	0.945	0.921	0.899
158	0.941	0.914	0.906	350	0.951	0.897	0.795
165	0.924	0.893	0.840	354	0.904	0.861	0.808
176	0.910	0.858	0.787	361	0.782	0.759	0.708
177	0.973	0.950	0.929	366	0.902	0.879	0.830
183	0.932	0.906	0.879	368	0.967	0.921	0.936
Means					0.895	0.860	0.824

actual tones chosen by Bach for doubling are better able to define the prevailing key.

With regard to the predicted prevalence of the mediant pitch compared to the subdominant pitch, the results remain consistent with Krumhansl's tonal hierarchy. In the case of the major key sample (Figure 2a), the distribution of doubled tones shows that the the mediant pitch is slightly more prevalent than the subdominant pitch. In the minor key sample (Figure 2b), the number of mediant and subdominant pitches are equivalent. The most

peculiar results pertain to the supertonic and submediant degrees in the major key data. The 2nd and 6th degrees are doubled more frequently than the subdominant, a fact that appears to be inconsistent with both the Krumhansl and Kessler key profiles and recommendations in traditional music theory.

It is difficult to devise an appropriate inferential statistical test for these latter observations since a number of confounding factors are involved. In the first instance, the relative frequency of the 2nd and 6th degrees may arise due to tonicization of the dominant and submediant pitches (the 2nd degree is the dominant of the dominant). Notice also that the organization of triads themselves tends to influence the doubling of various tones. The mediant degree, for example, appears in the *I*, *iii*, and *vi* triads. However, in each of these triads it is possible to double another pitch that has a higher value in the tonal hierarchy and so may play a greater key-defining role: the tonic (in the case of the *I* and *vi* chords) and the dominant (in the case of the *iii* chord). In chords where the subdominant pitch appears (*ii*, *IV*, *vii*) Krumhansl's tonal hierarchy would predict doubling of the subdominant since none of the other possible chordal tones (degrees 2, 6, or 7) has a higher rating in the key profiles. This predicted ranking can be seen in the minor key data, however, the major key data is the reverse of what is expected. Contrary to traditional music theory recommendations, it would appear that Bach is especially reluctant to double the subdominant pitch, although again, this interpretation is in need of an appropriate inferential statistical test. A further confounding factor arises from the different frequencies of occurrence for various diatonic chords. The heightened prevalence of the supertonic and submediant tones may be due to considerations of harmonic progression rather than tonicization or tonality. In short, a detailed comparison of the distributions is impossible without much more elaborate investigations of tonicization, the pitch structure of triads, and the relative frequency of diatonic chords. At a minimum, the results imply that the mediant pitch plays a greater role in chordal-tone doubling than has been traditionally suggested.

Conclusion

In light of the above tests, it appears that Krumhansl's tonal hierarchy provides a lucid and parsimonious account of chordal tone doublings in the practice of J.S. Bach. In the case of 44 chorales written in major keys, the distribution of doubled tones was found to correlate with Krumhansl and Kessler's key profiles at a remarkably large value of $r = 0.94$. When doubled-tones were eliminated from the works, a significant reduction in mean correlations was observed. These results are consistent with the view that doubled-tones play a greater key-defining role than other tones in the works. Moreover, it was shown that the actual tones chosen by Bach for doubling better correlate with the key profiles than other possible tones that may be doubled.

Overall, the results are consistent with the view that the primary musical goal in the doubling of chordal tones is to enhance the perception of the prevailing key. In this regard, the results affirm the view expressed by theorists that "key stability" is the preeminent principle shaping the choice of

doubled tones. More especially, the results indicate that the hypothesized enhancement of key perception in chordal-tone doubling is achieved using methods consistent with a *structural* view of tonality—that is, by choosing pitches that conform to the key prototypes determined experimentally by Krumhansl and Kessler. The principal recommendations offered by music theorists concerning the doubling of chordal tones can thus be seen to be partial descriptions of the major and minor key distributions shown in Figure 1: (a) avoid doubling nonscale pitches, (b) avoid doubling the leading tone, (c) doubling the tonic and dominant pitches is preferred.

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