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DIACHRONIC CHANGES IN JAZZ HARMONY: A COGNITIVE PERSPECTIVE

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THE PRESENT STUDY EXAMINES BOTH GRADUAL and rapid changes occurring in 20th-century jazz harmonic practice. A newly-assembled corpus of 1,086 jazz compositions was used to test the idea that jazz music exhibits a mid-century decline in traditionally “tonal” chord usage. Evidence was found for slow, incremental changes in zeroth-order chord quality distributions, consistent with gradual, unconscious changes in harmonic usage. Typical tonal chord-to-chord transitions became less common between the 1920s and the 1960s, consistent with the hypothesis of tonal decline. Finally, use of root motion of an ascending perfect fourth dropped suddenly in the 1950s, suggesting that chord-to-chord transitions might be more susceptible to rapid change than chord frequency. Possible constraints on stylistic evolution are discussed.

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Key words: corpus study, style change, implicit learning, transition probabilities, jazz harmony

MANY HISTORIANS AND MUSICOLOGISTS have emphasized the role of particular composers and theorists in shaping musical evolution (see, e.g., Hodeir, 1956). Diachronic changes in musical style have also been described in terms of slow, continual change and broad trends in time. Several empirical studies adopting the latter perspective have recently appeared. For example, Schellenberg and von Scheve (2012) suggest that increasing minor-mode use in popular music reflects a slowly increasing desire for emotional complexity, and Serra, Corral, Boguna, Haro, and Arcos (2012) examine gradual trends in loudness and timbre in popular music recordings. MacCallum, Mauch, Burt, and Leroi (2012) wonder whether individual decisions by a large population of real listeners could drive musical evolution, and evaluated a Darwinian model of musical change. Each of these approaches treats musical stylistic change as gradual and cumulative, resulting from population-level phenomena.

Nevertheless, it seems obvious that certain individual musicians have made lasting contributions to musical style. For example, in the past century, rapid stylistic changes seem to have been induced by musicians such as Arnold Schoenberg or Chuck Berry. At present, it is unclear how large-scale trends and individual contributions might interact in the evolution of musical style. Phrasing the question another way, to what degree are musicians the product of their musical culture, and to what extent are musical cultures directly shaped by individuals?

Similar questions about the causes of cultural change arise in the field of historical linguistics. Traditionally, language changes have been characterized as being either internally or externally motivated (Campbell, 1998; Marcel, 1975). Internal motivations are structural features of the language itself, often in interaction with the speaker’s cognitive, perceptual or anatomical characteristics. For example, phonemes might be modified to be easier to pronounce or distinguish (e.g., in assimilation or dissimilation processes), or verb endings might be regularized, hence adopting more economical forms. Processes such as these would be expected to result from long periods of gradual alterations in usage, emerging statistically at the population level. By contrast, externally-motivated language changes derive from outside the language structure itself, such as when loan words result from language contact (through geographical or situational means), or when social differentiation mediates the adoption of jargon or slang in some communities. One could consider activities of certain influential individuals or groups as being external motivations for some language changes, such as when Shakespearean coinages such as “assassinate” became widespread, or if an edict from the *Académie française* becomes widely adopted.

While cultural changes in general are invariably more complex than a simple “internal versus external” dichotomy might imply, the distinction may yet provide a useful way to think about both linguistic and musical style changes (see Meyer, 1989, pp. 106-122). If a music historian were to discover a sudden and dramatic change in a musical tradition, it would be natural to seek some external cause for the interruption. This could involve specifying a particular composer’s intent, pointing to a transformative composition, or referring

to a more general cultural or aesthetic movement. On the other hand, if only slow and gradual style change was observable, then the historian might instead wonder what internal characteristics of the musical structure might have caused the drift, and moreover if this drift was arbitrary or toward any particular goal.

In order to account for goal-directed gradual change, one would want to specify an interaction between a musical style structure and some stable, long-term constraint on musical composition, performance, or transmission. Possible contingencies could include the sound-processing characteristics of the auditory system (Moles, 1968; Parncutt, 1989; Huron, 1992, 2001; Snyder, 2001), a communicative imperative (Swain 1997; Temperley, 2004), an “axiom of constancy” (Meyer, 1989), a “historical context of continual change” combined with memory (Gjerdingen, 1988), algorithmic replication and differentiation (Dawkins, 1976; Jan, 2007, MacCullum et al., 2012), or continual differentiation of musical parameters (Meyer, 1989). A musical style structure which is somehow suboptimal might be seen as an internal motivation for musical style change (Meyer, 1967, p. 114).

Simply because musical enculturation is not identical from person to person, musical style changes could arise without external motivation. Particularly relevant are the processes by which music is learned, cognitively represented, and transmitted. In particular, statistical learning has been demonstrated in infants and adults listening to artificial finite-state grammars employing local dependencies (Altman, Dienes & Goode, 1995; Bigand, Perruchet & Boyer, 1998; Loui, Wessel, & Hudson Kam, 2010; Saffran, Johnson, Aslin, & Newport, 1999), as well as more complex transformational musical grammars (Dienes & Longuet-Higgins, 2004; Kuhn & Dienes, 2005; however c.f. Desmet, Poulin-Charronnat, Lalittle, & Perruchet, 2009). In line with such psychological research, recent attempts at modeling musical cognition have relied on statistical information extracted from large musical corpora (Huron, 2006; Temperley, 2007). Although statistical properties such as event frequencies and transition probabilities cannot capture all aspects of musical style, they may still describe an important component of musical culture that is learned and passed on. The present study will make use of such representations in order to investigate the interaction of gradual and immediate stylistic changes in 20th century jazz.

External influences on jazz style are not difficult to identify. Jazz can be seen as a byproduct of specific cultural and geographical constraints, an amalgam of New Orleans marching bands, African rhythms (Gridley &

Rave, 1984), Southern Delta blues, and regional Creole influences, among other factors (Hodeir, 1956). The eventual collation of these in the Storyville district of New Orleans is seen by many jazz historians as the critical point at which jazz began in earnest (Schuller, 1968). When Storyville closed and unemployment for young musicians rose in the southern United States, a “great migration” to Chicago facilitated the birth of a new type of jazz music in the early 1920s (Adero, 1993; Grant, 1972; Grossman, 1989; Schuller, 1968). The history of jazz style since this time has been strongly influenced by individual musicians such as Louis Armstrong (Harker, 2008; Schuller, 1968), John Coltrane (Porter, 1985; Woideck, 2008), and Miles Davis (Magee, 2007), among others.

Although important individuals and events may have had transformational effects on jazz style, jazz harmony nevertheless relies on a set of well-defined harmonic patterns that might be implicitly learned and could exhibit gradual shifts in usage. With this in mind, we empirically investigated one particular change in jazz harmonic practice: the commonly-held notion that traditional tonal chord use became less prevalent over the course of the 20th century. Jazz music during the 1920s through the 1940s drew heavily from the tonal idioms of swing and popular song (see Forte, 2001; Wilder, 1972). Bebop musicians commonly borrowed chord progressions directly from the Great American Songbook for their compositions. However, the 1950s and 1960s saw several new styles of jazz arise that began to diverge from the music’s tonal origins (Lopes, 2002).

Modal jazz, associated with musicians such as Bill Evans and Miles Davis, emphasized the melodic aspects of improvisation over the tonal harmonic progressions characteristic of bebop (Barrett, 2006; Kernfeld 1981; Tirro, 1977). Instead of functional harmony, some modal jazz musicians made use of what George Russell termed “chordmodes” as a framework (Russell, 2001; Kernfeld, 1981). Several other styles, such as hard bop, soul jazz, avant-garde, and free jazz emerged during the late 1950s and early 1960s, each associated with different origins, important figures, and stylistic elements (Gridley, 1978). The year 1959 in particular has popularly been described as a pivotal year in this “post-bop” transition, in part because it coincided with the recording or release of some of the most influential albums in jazz history: Miles Davis’s *Kind of Blue*, Dave Brubeck’s *Time Out*, Charles Mingus’s *Mingus Ah Um*, Ornette Coleman’s *The Shape of Jazz to Come*, and John Coltrane’s *Giant Steps* (Barber, 2004; Bernays, 2010; Holaway, 2004; Shriver, 2009).

Utilizing a newly-compiled corpus of jazz chord progressions, we characterized the nature of this style change while testing three simple hypotheses: First, we expected to find a change in harmonic usage between 1924 and 1968. Second, we predicted that changes in chord usage would reflect a “tonal decline” in which chord progressions with traditional tonal function would become less common. Third, we empirically tested the popular idea that the year 1959 was pivotal in this transition. Within this framework, we explored whether changes in jazz harmonic practice were largely the result of a gradual shift, or if there were dramatic changes in musical style. To anticipate our results, we find evidence for both gradual changes in jazz harmonic usage and for an abrupt change in the late 1950s.

Assembly and Validation of a Jazz Corpus

CORPUS SELECTION

In the case of jazz music, identifying authoritative source material is not necessarily straightforward. The jazz canon is quite diverse, drawing on several popular musical traditions as well as original compositions by jazz artists. A film-derived jazz standard such as Irving Berlin’s “Cheek to Cheek” might exist in the form of the composer’s original notated melody and chords, an arranger’s orchestrated film score, a recording of Fred Astaire’s original vocal rendition, or a published piano arrangement for popular use. Complicating matters further, the jazz idiom itself is characterized by improvisation and explicit *departures* from notated scores. This means that any jazz recording of “Cheek to Cheek” by musicians such as Ella Fitzgerald, Chet Atkins, Count Basie, Oscar Peterson, or Joe Pass might also be considered a valid representation of jazz practice.

Instead of authoritative scores, jazz musicians have worked with oral traditions, aided by a form of abbreviated notation known as lead sheets. Both authorized and unauthorized collections of lead sheets known as fake books have been published, traded, and shared by jazz musicians since the 1920s (Kernfeld, 2006). Although often of unknown origin and editorship, these scores more closely reflect jazz practice than would any “original” edition. We identified an Internet forum over which jazz musicians actively exchange electronically-encoded lead sheets, including a fake book of 1,186 jazz pieces (iReal b, 2011). The size and ready availability of this database make it attractive source material for a corpus analysis of jazz harmony.

Although this data source is convenient and enables corpus-based research that might not otherwise be possible, some caveats should be mentioned. This corpus

reflects a standard repertory that has been filtered through different lead sheet transcribers and curated by anonymous modern editors. These scores also do not necessarily represent what a historically situated listener would have been regularly exposed to. Nonetheless, the corpus as a whole could still prove useful, provided the selection process had no systematic biases toward scores with certain harmonic practices. As an additional safeguard, we analyzed only the essential elements of the harmony: basic chord qualities and root motion.

CONVERSION AND VALIDATION

Each of the 1,186 digital lead sheets specified a title, composer, time signature, chords, durations, and indicators of form (such as section labels, repeats, and codas). In order to facilitate analysis, we used the Humdrum music encoding system (Huron, 1995), creating a new kind of Humdrum representation, `**jazz`. A series of computer programs written in Bash and AWK extracted and subsequently re-encoded the rhythmic and harmonic information. Following this initial automated step, we manually corrected various translation errors. Reference records denoting composers, lyricists, and dates of first recording were added after consulting several sources. The `**jazz`-encoded corpus (henceforth “iRb corpus”) contains 81,383 data records representing 47,372 chord tokens. The iRb corpus has been made available at <http://music-cog.ohio-state.edu/>.

Multiple types of error could compromise a corpus study, including both errors present in the electronically-encoded scores and errors introduced or compounded by analysis of the corpus (Huron, 1988). Moreover, the sampling characteristics of the pieces in the corpus ought to represent the jazz canon of interest. Given the anonymous source of the scores, a rigorous validation was warranted.¹

To estimate encoding error rates in the iRb corpus, we established a reference set of 20 readily-available published fake books (Table 1). As previously discussed, the notion of an authoritative version of a piece is not easily defined for jazz: different fake books might specify different chord changes for a given piece, with none being considered “incorrect.” We therefore considered all fake books to have the same *a priori* legitimacy; if an iRb score was consistent with any one fake book, it was considered valid. While many of these reference fake-books are of unknown origin and questionable legality,

¹ An earlier version of the iRb was validated using a similar procedure reported in Shanahan and Broze (2012). The current validation reflects an independent validation of a manually-corrected database.

TABLE 1. *List of Fake Books Consulted for Corpus Validation.*

Anthologie des Grilles de Jazz
Real Book of Blues
Cuban Fake Book
Colorado Cookbook
The Bill Evans Fake Book
The Hal Leonard Real Jazz Book
Library of Musicians Jazz
Jazz Fake Book
Jazz LTD
Latin Real Book
New Real Book 1
New Real Book 2
New Real Book 3
Real Book 1
Real Book 2
Real Book 3
The Slick Book
Standards Real Book
The Book
The Other Book

their wide use nevertheless seemed to justify their inclusion as sources representative of jazz practice.

While reharmonization in jazz is often spontaneous and unpredictable, it is typically not arbitrary. There exist several common traditions and well-defined rule systems that govern reharmonization practices (Aeber sold, 2000; Felts, 2002; Järvinen, 1995; Levine, 1995; Steedman, 1984). An example of typical reharmonization would be the “tritone substitution,” in which a dominant-seventh chord on the fifth scale degree (e.g., G7 in the key of C) is replaced with a dominant seventh chord a tritone away (Db7 in the key of C). In addition to simple substitutions, one sonority could be represented by several alternative notations. For example, “C7sus4/G” could be respelled as “G-7(11)” without changing its basic meaning (see Levine, 1995, p. 259). An appropriate validation process would be sensitive to these peculiarities of the jazz idiom.

Each chord in the iRb corpus was individually assigned to one of eight quality categories: major, minor, minor-seventh, dominant-seventh, half-diminished (or minor-seventh with lowered fifth), diminished, suspended, and augmented. Major, diminished, suspended, and augmented types included their seventh-chord variants, and additional extensions of these basic qualities (e.g., 9ths or 11ths) were ignored. From the corpus, 250 chords were selected at random and compared against the 20 reference fake books. Each chord was classified according to the following five categories: (1) “match”: identical notated chord root (relative to the published key) and quality (ignoring extensions); (2) “respelling”: equivalent chord in

an alternative notation; (3) “reharmonization” typical of jazz (as specified by Levine 1995); (4) “wrong chord”: root or quality error that could not feasibly represent jazz practice; (5) “insertion”: error in which the chord did not appear in the source material at all.

Of the 250 chords sampled for validation, 24 were from pieces not included in the 20 fake books. These selections were omitted from the validation, leaving 226 chords for analysis. Of the remaining chords, we identified 198 identical matches (87.6%), no respellings (0%), 15 reharmonizations (6.6%), 13 wrong chords (5.7%), and no insertions (0%). This indicates considerable agreement between the iRb corpus and published sources, but also that subjective reharmonizations have apparently shaped the corpus to some extent. That is, broad-scale musical structures appear to be largely intact. Considering wrong-chord errors alone, the estimated chordwise error rate is 5.7%, with a 95% binomial upper confidence bound of 9.0%. If randomly distributed, these types of errors would likely represent white noise and/or loss of analytical power, depending on the type of study conducted.

SAMPLING CHARACTERISTICS

Because the iRb corpus was assembled from scores traded by present-day jazz musicians, it possibly represents a bias toward those pieces that remain in active use as part of the jazz canon. Additionally, it is possible that there are unpredictable biases introduced by members of the jazz community. For instance, Thelonious Monk is the composer appearing most frequently in this collection, while works by other, arguably more influential or prolific composers such as Duke Ellington are less common. Nevertheless, there seems to be substantial overlap between the iRb corpus and other fakebooks. Of the 250 individual pieces involved in chord validation, only 24 (9.6%) could not be found in the reference set. For additional confirmation, we consulted a list of the 1000 most recorded jazz standards (Wilson, 2005), finding that 640 (64.0%) of them are included in our database, a substantial overlap. These concordances led us to believe that the iRb corpus is a good representation of jazz practice.

Tests for a Decline in Traditional Tonal Chord Use

Functional tonality is a complex phenomenon that is not easily defined (see Dalhaus, 1990; Hyer, 2002). Even if a sophisticated model of jazz tonality were to be constructed, the iRb45 corpus would still offer only a basic harmonic perspective. Accordingly, we investigated jazz style changes by adopting simplified markers of “tonality”

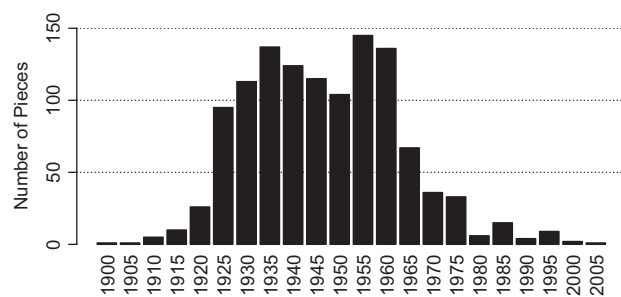


FIGURE 1. Distribution by year of composition of the 1,186 pieces in the complete iRb corpus, organized into 5-year bins. Bins are labeled by their starting year. The majority of included works were composed between the 1920s and the 1970s. For diachronic analysis, a 45-year subsample (iRb45) was created, incorporating pieces composed between 1924 and 1968.

derived from typical tonal chord progressions. First, yearly distributions of chord quality frequency were investigated to test for any change at all. Second, frequencies of chord-to-chord quality transitions were compared for early and late epochs. Third, the incidence of root motion by ascending perfect fourth was traced, along with chord progressions of the *ii7 - V7* and *V7 - I* type. It was hoped that testing these simple hypotheses would enable a more general characterization of jazz harmonic practice.

DISTRIBUTION OF CHORD QUALITIES

Our first hypothesis simply proposed that jazz harmonic usage would change between 1924 and 1968. We employed a measure of musical syntax with plausible psychological relevance: the probability of encountering a chord of a particular quality. Listeners appear to make use of mental representations of such “zeroth-order” probabilities (see, e.g., Krumhansl, 1990; Huron, 2006, p. 73). One might expect that changes in harmonic usage would have an impact on zeroth-order probabilities of encountering chords of a given quality.

After expanding indicators of form, the iRb45 corpus contains 53,125 individually notated chord tokens, the most frequent being the dominant-seventh, occurring 21,399 times and representing 40.3% of chords encountered. Next most frequent are minor-seventh (13,954 occurrences, 26.3%) and major chords (11,732 occurrences, 22.1%). Considerably less common are half-diminished chords (2,184, 4.1%), minor chords (2,065, 3.9%), and diminished chords (1,187, 2.2%). The remainder are suspended (540, 1.0%), or augmented (64, 0.1%). Overall chord frequencies are plotted in Figure 2.

A multinomial logistic regression modeled the change in chord distribution from 1924 to 1968, with year as

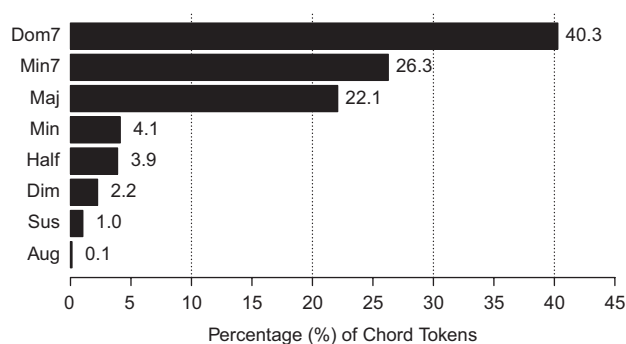


FIGURE 2. Chord qualities represented in the complete iRb corpus, represented as proportions. Dominant-seventh chords, minor-seventh chords, and major chords constitute the majority of all chords encountered.

the only explanatory variable; the fit was found to be statistically significant, $\chi^2(7) = 411.78$, $p < .001$. The resulting fit is plotted in Figure 3. Post-hoc analyses of individual trends revealed decreases in the prevalence of dominant-seventh ($z = -3.73$, $p < .01$), major ($z = -4.07$, $p < .01$), and diminished chords ($z = -11.0$, $p < .01$). By contrast, minor-seventh ($z = 4.23$, $p < .01$), minor ($z = 8.96$, $p < .01$), and suspended chords ($z = 12.0$, $p < .01$) exhibited statistically significant increases in prevalence over time. Half-diminished chords showed no significant change, $z = 0.82$. Due to an underrepresentation in the corpus, augmented chords were not separately tested.

Given the very large sample size, statistical significance of these results should not be surprising. Nonetheless, the results are consistent with the hypothesis that chord usage changed in jazz between 1924 and 1968. The pattern of change appears to be slow and gradual overall. The post-hoc analyses reveal at least three interesting characteristics. First, the chords that traditionally represent the “Dominant” functional category in traditional harmony (dominant-seventh and diminished) both exhibit declines in usage over the studied timespan (see Laitz, 2012). In particular, decreasing diminished chord use could reflect a declining trend in applied Dominants typical of many 1920s pieces.² This would be consistent with the idea that traditionally tonal chord use became less common.

Second, these results permit comparison with recent evidence collected by Schellenberg and von Scheve (2012), which indicated that minor-mode usage in popular music rose from 1965 to 2009. These authors

² For example, “Birth of the Blues” (1926) and “Makin’ Whoopee” (1928) both begin with *I - viio7/ii - ii* progressions.

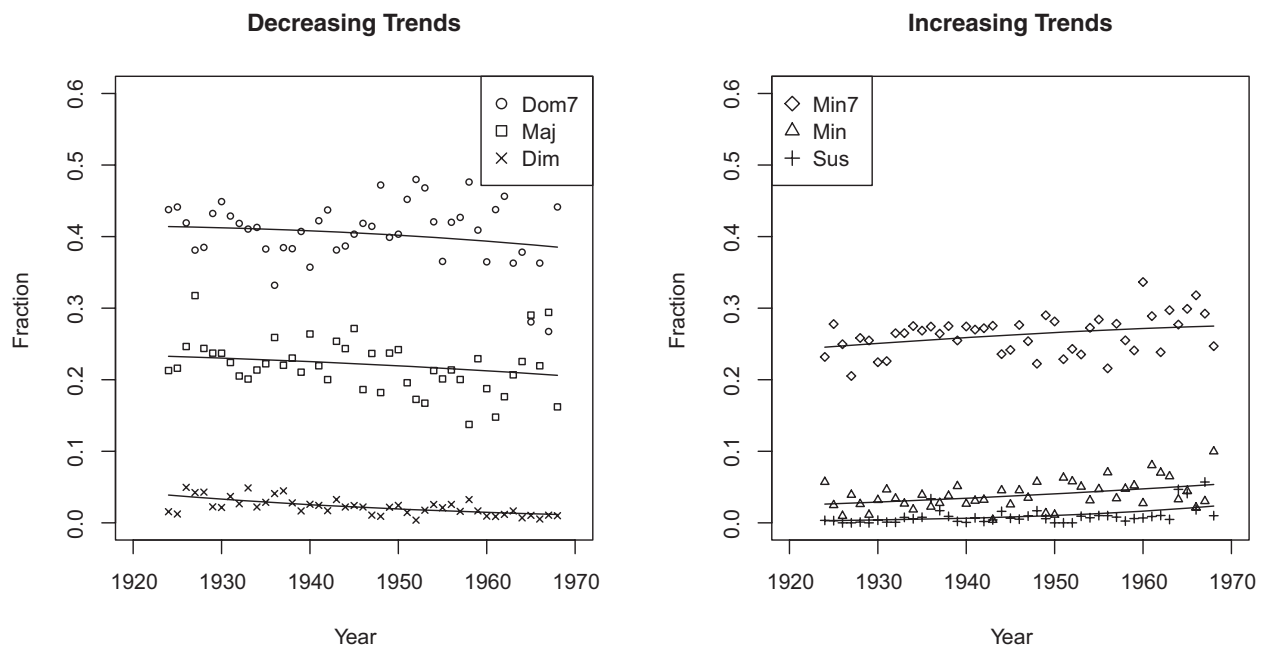


FIGURE 3. Prevalence of the six most common chord qualities in the iRb45 corpus, plotted over time (1924–1968). Multinomial logistic models were fit to the data series; chord types are separated by trend direction for legibility. An omnibus test revealed statistical significance for a fit using eight chord qualities, $\chi^2(7) = 411.44$; $p < .0001$. For clarity, not shown are half-diminished chords (which exhibited no significant trend) and augmented chords (for which little data was available).

suggested that this could reflect an increasing desire for complexity of musical structure or emotional expression. Potentially, this interpretation could also be relevant to jazz harmony: In the iRb corpus, both major and dominant-seventh quality chords decline in usage, while minor and minor-seventh chords increase in frequency.

Third, the prevalence of suspended chords increases, especially in the late 1960s. This particular chord type is characteristically used as an independent sonority in modal jazz styles, typically indicating use of the Dorian mode (Levine, 1995; Pease & Pullig, 2001). For example, a suspended chord in modal jazz might be voiced in a “quartal” configuration, such as was employed by Bill Evans on many of the *Kind of Blue* recordings or by McCoy Tyner when playing with John Coltrane. The rising popularity of suspended harmonies could be construed as reflecting an increase in modal jazz compositions.

In all, these results indicate that jazz harmonic practice experienced some gradual changes in chord usage, potentially due to random drift or internal motivations for style change. However, they do not support the idea that 1959 was a particularly important year for jazz harmonic practice. Except for a possible increase in suspended chord use around 1965, the overall

zeroth-order chord quality distribution appears not to have a sharply altered trajectory at any point. From a perceptual perspective, this would mean that a listener who implicitly learned zeroth-order chord quality frequencies in the 1930s would be able to apply this knowledge equivalently well in the 1960s.

It is worth noting that zeroth-order probabilities such as these do not bear a necessary relationship to tonality *per se*. For example, the iRb chord frequencies are quite different from those found in other “tonal” repertoires. The iRb corpus chords are approximately 40% dominant-seventh, 30% minor-seventh, and 22% major, but chords from a comparison sample of 185 Bach chorales are only 13% dominant-seventh, 8% minor-seventh, and 47% major. Despite the marked difference in zeroth-order distributions of chord qualities, both the jazz and Bach chorale samples would be considered largely “tonal.” That is, instead of simple chord quality distributions, functional tonality seems to depend more on the transitions *between* chords. This will be the subject of the next tests for changes in harmonic use.

CHORD-TO-CHORD TRANSITION TYPES

While previous corpus studies of harmonic motion have relied on Roman-numeral analyses performed by

TABLE 2. Most Common Two-Chord Transitions in the iRb45 Corpus.

Two-Chord Event	Occurrences	Percentage	Harmonic Heuristic
Min7 - P4 - Dom7	7,925	17.2%	"ii7 - V7"
Dom7 - P4 - Maj	5,469	11.9%	"V7 - I"
Dom7 - P4 - Min7	2,939	6.4%	"V7/ii - ii7"
Dom7 - P4 - Dom7	2,183	4.7%	"V7/V - V7"
Half - P4 - Dom7	1,755	3.8%	"ii7(b5) - V7"
Min7 - P4 - Min7	1,019	2.2%	"vi7 - ii7"
Maj - M6 - Min7	843	1.8%	"I - vi7"
Maj - M2 - Min7	843	1.8%	"I - ii7"

Note. Every two-chord transition in the iRb45 corpus was recorded in terms of the qualities of participating chords and the ascending interval between them. Eight quality categories were used: major, minor, minor-seventh, dominant-seventh, half-diminished, fully-diminished, suspended, or augmented. In all, motion by ascending P4 overwhelmingly predominated, representing half of all root motions. To aid comprehension, traditional harmonic interpretations are provided only as heuristics. It should be emphasized that these are not the only descriptors for such progressions, nor do they necessarily represent their functional role in the pieces sampled.

experts (e.g., de Clerq & Temperley, 2011), we opted to employ an entirely automated approach. In addition to avoiding possible editorial bias, this methodological choice is especially appropriate to jazz. Because jazz harmony tends to make extensive use of applied dominants and often features fluctuating tonal centers, describing harmonies in terms of a piece's nominal key can be somewhat problematic. Moreover, many pieces employ "open" key signatures with no accidentals, particularly those from the "post-bop" era of the late 1950s and early 1960s. For example, John Coltrane's "Giant Steps" has a key signature with no accidentals, but is certainly not well-described as being in C major. This issue is present in modal compositions as well: Miles Davis's "So What," for instance, is commonly described as being in D-Dorian, a subtle distinction not captured by key signature alone. Therefore, we considered solely root motion and chord quality in our analysis of chord transitions, and again ignored all chordal extensions. This allowed for a modular analysis of harmonic combinations, regardless of their relationship to an overarching tonic.

To explore the iRb45 corpus, every chord-to-chord transition was expressed as three pieces of information: the quality of the first chord, the interval separating the chord roots, and the quality of the second chord. Progressions were considered with no reference to their metric position, and repeated chords (i.e., those separated by a P1) were discarded. Intervals were measured in 12-tone chromatic space and re-expressed as ascending simple intervals. The most common 2-chord sequences are given in Table 2.

CHORD QUALITY TRANSITIONS

Listeners might be expected to use information about the current chord quality to form expectations about what chord quality will follow, amounting to a representation

of a set of transition probabilities (Temperley 2007; de Clerq & Temperley, 2011; Karlin & Taylor, 1998; Huron, 2006). To compute a transition probability matrix, one would first tabulate the occurrences of every chord-to-chord transition, or "bigram," in a 2x2 table, with each row corresponding to a different starting chord and each column representing a different second chord. Then, conditional transition probabilities can be computed by dividing these bigram counts by the row totals. Transition probability matrices such as this have proven very helpful to the computational modeling of composition, accompaniment, and music cognition (e.g., Berger, 2004; Cope, 1984; Simon, Morris, & Basu, 2008). In order to facilitate future study, an overall quality-to-quality transition probability matrix for the iRb45 corpus is given in Table 3.

We hypothesized that bigrams associated with traditional functional tonality would become less common. Among the three most common chord qualities (dominant-seventh, minor-seventh, and major), two transitions in particular represent typical tonal functions (see Laitz, 2012). Dominant-seventh to major occurs in V7 - I, a typical tonal cadence signifying motion from dominant function to tonic function; minor-seventh to dominant-seventh occurs in ii7 - V7, which could represent motion from predominant function to dominant function. While these particular progressions are not the only occasions where these quality-to-quality transitions would occur, a marked decline in their use might still produce a measurable effect.

We therefore created two matrices representing the occurrence of each quality-to-quality bigram in the first ten years (1924-1933) and last ten years (1959-1968) covered by the iRb45 corpus. Heat maps for these counts are shown in Figure 4, with dark regions indicating low activity, and bright regions indicating high activity. The most obvious characteristic of the bigram

TABLE 3. Quality-to-Quality Transition Probabilities for the iRb45 Corpus.

		Second Chord								Bigram count
		Dom7	Min7	Maj	Min	Half	Dim	Sus	Aug	
First Chord	Dom7	.240	.323	.350	.041	.032	.009	.005	.000	18,937
	Min7	.707	.161	.041	.018	.038	.024	.011	.000	12,777
	Maj	.350	.363	.100	.027	.073	.065	.015	.006	9,121
	Min	.340	.253	.142	.075	.162	.018	.007	.002	1,460
	Half	.887	.028	.031	.023	.026	.003	.001	.000	2,129
	Dim	.109	.592	.240	.017	.028	.006	.008	.000	1,119
	Sus	.361	.080	.461	.003	.028	.015	.053	.000	399
	Aug	.047	.078	.875	.000	.000	.000	.000	.000	64

Note. Transition probabilities are raw chord quality bigram counts normalized by row. For example, of the 2,129 bigrams beginning with a half-diminished chords, 88.7% (1,888) of them ended with a dominant-seventh chord. Equivalently, a half-diminished chord would be expected to proceed to a dominant-seventh chord 88.7% of the time.

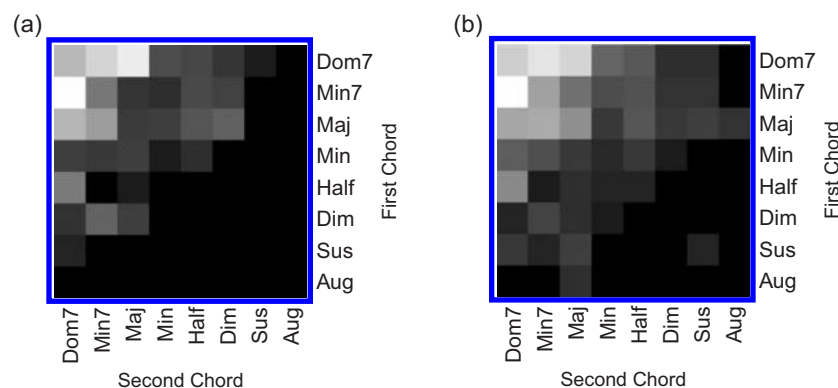


FIGURE 4. Heatmaps depicting chord quality bigram frequencies for (a) the years 1924–1933 and (b) the years 1959–1968, corresponding to the first and last ten years covered by the iRb45 corpus. Each two-chord sequence was categorized according to the quality of the first and second chord of the pair; the heatmaps represent probability that a given bigram will be of the given type. The dark, “cool” regions specify low probability, whereas brighter, “hot” regions indicate higher probabilities. On the whole, chord-to-chord quality transitions become less constrained, with later years allowing more types of transitions. Specifically, transitions such as dominant-seventh to major exhibit decreases in prevalence, suggestive of a decline in traditional tonal syntax. (a) 1924–1933 (b) 1959–1968

distribution is the greater variety of transition types in later years. Both major and minor-seventh chords, for instance, were largely constrained to progress to a dominant or minor-seventh chord from 1924–1933, but were more free to move to a major chord in the years 1959–1968. Conversely, major chords in the early epoch were usually approached by a dominant-seventh chord, but could be approached by a wide variety of chord qualities in the later epoch.

From the first ten years to the last ten years of the iRb45, dominant-seventh to major bigrams declined in frequency more than any other bigram, from 16.9% to 11.2%, $\chi^2(1) = 116.67$, $p < .001$. Minor-seventh to dominant-seventh bigrams decreased second-most in frequency, from 20.1% to 16.9%, $\chi^2(1) = 28.32$, $p < .001$. These results are consistent with the idea that traditional functional tonal gestures would become less

common. Meanwhile, the transitions that *increased* the most in frequency were major to major, minor-seventh to minor-seventh, and minor-seventh to major.³

In the previous analysis of zeroth-order chord frequencies, we had conjectured that the increased occurrence of suspended chords could reflect their use in modal jazz as independent sonorities. The bigram frequencies shown in Figure 4 correspond with this interpretation. Suspended chords appearing from 1924–1933 almost invariably lead to dominant chords, meaning they could be described as having a well-defined

³ These increasing transitions are somewhat more difficult to interpret, in part because composers were apparently less constrained in their compositional choices, in part because these matrices discard root motion information, and in part because notational conventions might have changed.

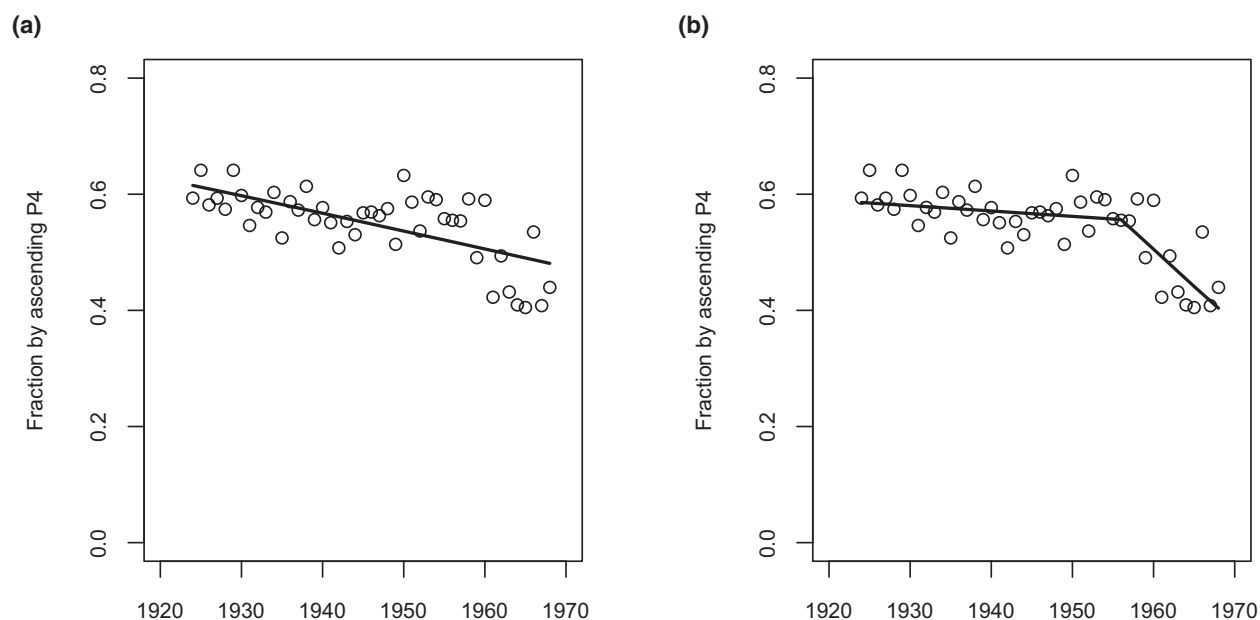


FIGURE 5. Fraction of chord-to-chord transitions exhibiting root motion of an ascending perfect fourth (P4), measured using the iRb45 corpus between the years 1924 and 1968. Plot (a) is a logistic regression exhibiting a decline in P4 root motion, $z = -15.31$, $p < .01$. Adding an additional parameter to account for a sudden change in 1959 significantly improved the fit, $\chi^2(1) = 104.77$, $p < .01$. The maximum likelihood estimate of the year of change was 1956, shown in plot (b). Note that this trajectory is not meant to be predictive.

function (e.g., as a 4–3 suspension over a V7 sonority). However, suspended chords from 1959–1968 are free to proceed to several other chord types, including other suspended chords.

CHORD-TO-CHORD ROOT MOTION

Traditional functional tonality is associated with certain patterns of root motion between adjacent chords. Tonal root motion can be categorized in terms of three different interval types: fourth/fifth, third/sixth, or second/seventh (Rameau, 1722/1971). In particular, root motion by ascending perfect fourth (P4) is widespread in both traditional tonal works and in tonal jazz music (see Table 2).⁴ Notably, the five most common two-chord transitions involve an ascending P4, and this interval accounts for a full 55.8% of all transitions. One could therefore predict that a decline in tonal chord usage might be accompanied by a decrease in ascending perfect fourth root motion.

In order to investigate whether P4 progressions became less common, a logistic model was fit to the time series from 1924 to 1968, with year as the sole predictor.

⁴ For example, standards such as “Autumn Leaves” and “All the Things You Are” are composed almost entirely of ascending perfect fourth root motion, and this tonal logic also gives rise to the ii-V-I chord progressions widespread in swing and bebop jazz idioms (see Levine, 1995).

A statistically significant trend was identified wherein P4 progressions decrease in prevalence ($z = -15.31$, $p < .01$), consistent with the hypothesis of a shift away from traditional tonality. Figure 5a displays the fitted logistic regression line.

After examining the data, it would appear that a linear relationship might not be the best way to describe the trend: An alternative interpretation would be that the rate of decline in P4 root motion usage changed suddenly around 1959. It is possible to formulate this prediction as a question of statistical model-building. Specifically, we would like to know whether a model with a single linear predictor (the year of composition plus intercept) could be significantly improved by adding an additional parameter representing a pivot year for trend change. Apart from this alteration, the regression line ought to be continuous, with no break. This would suggest adding a predictor variable to the model that would induce a different slope if the year is after 1959. This revised model resulted in a statistically significant improvement in fit, $\chi^2(1) = 104.77$, $p < .01$, consistent with the view that there was a relatively rapid change in jazz harmonic usage.⁵

⁵ More specifically, a new predictor variable was added which was equal to zero for each year up to 1958, equaled 1 in 1959, 2 in 1960, and so on.

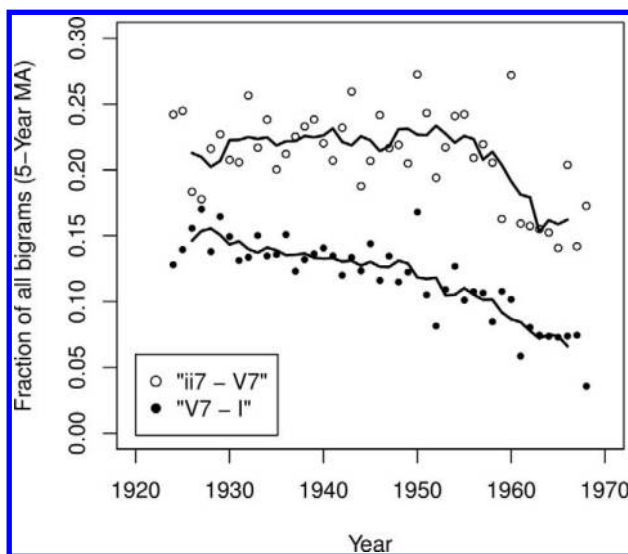


FIGURE 6. Changing prevalence of the two most common two-chord events in the iRb45, with five-year moving averages. Both “ii7 - V7” (Min7 - P4 - Dom7) and “V7 - I” (Dom7 - P4 - Maj) exhibited statistically significant declines in usage, logistic $z = -7.696$ and -14.92 , both $p < .001$.

The fact that the changing-slopes model reflects the data better than a constant slope model is consistent with the third hypothesis that 1959 was a pivot point in jazz harmonic practice. However, this method did not test whether 1959 was the inflection point instead of some other year. To do this, one would estimate which year is the best inflection point, given that one exists. The change point’s maximum likelihood estimate was found to be 1956 (Figure 5b), with a 95% confidence set of {1955, 1956, 1957}.⁶ It would seem that the rapid change in harmonic practice, if it occurred, might have taken place before 1959.

This change in P4 usage largely reflects two particular transition types: Min7 - P4 - Dom7 and Dom7 - P4 - Maj, representing ii7 - V7 and V7 - I chord progression types respectively. The trajectory of these transitions is plotted in Figure 6. Both exhibit statistically significant declines in prevalence over time, logistic $z = -7.70$ and -14.92 , both $p < .001$. Interestingly, the cadence-like V7 - I progression type appears to have declined earlier and more gradually than the ii7 - V7 progression type. A more in-depth analysis of changes such as these could

⁶The maximum likelihood estimate of the change point is the year which produces the best-fitting model of all years represented by the iRb45 corpus (i.e., the year which minimizes the logistic model’s residual deviance). The approximate 95% confidence set is based on inverting the Wilks chi-squared likelihood ratio test for change point location, given that the change point exists (see Feder, 1975; Haybach & Kuechenhoff, 1997; McCullagh & Nelder, 1989).

ultimately provide a more complete picture of style change in jazz. In particular, because the iRb45 constitutes an ad hoc sample, converging evidence from other data sources could clarify how much these results reflect jazz practice more broadly defined.

Discussion

This corpus study identified measurable diachronic style changes in jazz harmony. Changes in zeroth-order chord quality distributions suggested that only small, gradual alterations occurred between 1924 and 1968. This is consistent with the idea that cumulative, internally-motivated style changes might have played a role. Additionally, studies of chord quality transitions and of perfect-fourth root motion suggested a decline in traditionally “tonal” chord use. Harmonic usage appeared to become less constrained overall. Finally, we tested the popular idea that 1959 was a pivotal year in this transition, due to the influential release of modal and free jazz albums such as Miles Davis’s *Kind Of Blue* and Ornette Coleman’s *Shape of Jazz to Come*. Perfect-fourth chord-to-chord root motion began to decline around 1956, failing to support the idea that 1959 was a crucially influential year in jazz harmony.

This rapid stylistic change might reflect external events, such as a loss of several central figures in the genre, the deliberate use of novel harmonic approaches, several iconoclastic releases, or a broader cultural shift in the late-1950s and early-1960s that encompassed many socio-political and economic factors. As Meyer (1967) writes, “artists shape, and at the same time, are shaped by, culture” (p. 108). For example, free jazz pioneer Cecil Taylor released his first album in 1956, and hard bop trumpeter Clifford Brown and swing band-leader Tommy Dorsey unexpectedly died in the same year. Additionally, alto saxophonist Charlie Parker died in 1955. A monumental figure in jazz, Parker is strongly identified with bebop, a jazz style rooted in tonal harmonic traditions. Because Parker was widely respected and imitated, his departure from the jazz scene might have led musicians to seek other sources of inspiration. On the other hand, the present result could simply reflect sampling bias resulting from curatorial decisions: After 1955, there would be no more Charlie Parker compositions to include in a fake book such as the iRb corpus.

There are innumerable other possible external motivations for the late-1950s shift. During this period, jazz musicians became increasingly likely to write their own compositions, rather than to reinterpret the works of others (Lopes, 2002). Moreover, compositional demands changed as jazz music moved away from swing dance

halls and into clubs. One could argue that the relentless pursuit of Modernist innovation in jazz music led to an explosion of different styles sharing this aesthetic. Free jazz, along with avant-garde styles in general, has often been linked to political and social movements such as the civil rights movement (see Gridley, 2007). From a jazz historical perspective, our results should be interpreted as being consistent with many such motivations for the observed stylistic change.

Apart from affirming commonly held ideas about jazz history, the present study offers a perspective on style change more generally. Evidence both for *gradual* stylistic change and *rapid* stylistic change were found by analyzing different aspects of the same basic musical elements: chords. Curiously, the zeroth-order distribution of chords seemed to exhibit relatively little change from 1924 to 1968, even as patterns of first-order transitions between chords showed rapid change. Why should this be so?

One could imagine many possible reasons why zeroth-order probabilities of musical events would be relatively constant. A psychoacoustic account might suggest that a perceptual feature such as auditory roughness (i.e., dissonance) could play a role in constraining musical choices. For example, one could suggest that dissonant sounds tend to be avoided, and compositions are constructed to achieve a sort of “optimal consonance.” However, this could not explain why chord frequencies would differ so widely between genres. Instead, explanations based on implicit and explicit learning of one’s cultural environment seem more attractive.

One cultural-learning explanation would be based on musical perception and evaluation processes. Experimental evidence has indicated that cognitive representations of musical event distribution can be implicitly learned early in life (see e.g., Saffran et al, 1999). Potentially, representations of zeroth-order probabilities could be subsequently used in tasks relating to aesthetic judgment or music creation. If so, listeners or musicians might tend to reject music that does not conform appropriately to their expectations, hence promoting continuity of zeroth-order event distributions in musical practice.

The important role of improvisation in jazz performance could also explain why zeroth-order chord frequencies would be conserved. Jazz musicians who play chordal instruments must learn to play a great number of chords in several different voicings. Moreover, accomplished players spontaneously recall and apply these voicings during performances. Such competencies would presumably have corresponding neural encodings in the

form of motor routines, the relative strength of which would reflect their frequencies of use. To the extent that such explicitly-learned representations form a jazz musician’s working vocabulary of chords, improvising musicians might tend to favor more strongly-encoded chords simply because they are easier to employ.

Additionally, one could make a more general conjecture about musical evolution: Those styles that rely on cooperative improvisation ought to be more resistant to rapid style change than those that do not. Communities of improvising musicians rely on a shared set of musical style structures, representing a sort of “cultural redundancy” (see Meyer, 1967, p. 282). Not only would each musician’s individual vocabulary tend to have self-reinforcing tendencies, if cooperatively improvised music is to be coherent when performed, one would expect conservatism in style elements such as chord frequencies to prevail.

Note that zeroth-order probabilities could also be epiphenomena of higher-level sources of constancy, such as a relatively fixed set of chord progressions, harmonic schemata, or even cognitive representations of higher-order transition probabilities.⁷ After all, chord sequences could be implicitly learned as well as individual chords, and improvising musicians typically incorporate multi-chord “licks” in their vocabularies. An improvising trumpeter with a well-learned set of multichord fingering sequences would tend to produce melodies with stable zeroth-order note probabilities purely as a side effect of these higher-order representations.

While the above accounts of zeroth-order continuity might be plausible, they do not explain why first-order chord transitions would be more susceptible to rapid change. One possible explanation would be based on the cognitive processes of composition. A composer would require some understanding of the elements of a harmonic system as well as the relations between them, and these might have different cognitive representations. It seems reasonable (or even necessary) that we would be more tolerant of changing relationships between objects than changes in the objects themselves; while relationships are often ephemeral, objects tend to persist. Potentially, similar reasoning could apply to chordal composition processes as well.

A possible information-driven explanation would point out that longer and longer sequences of events require exponentially expanding resources to fully describe. For example, eight possible chord qualities

⁷ For example, a Markov process is fully defined by a set of transition probabilities, but also has a stationary zeroth-order limiting distribution (see Karlin & Taylor, 1998).

would lead to sixty-four possible bigrams and over four thousand possible tetragrams, even when ignoring root motion. Not only would it be more difficult to store information about higher-order sequences, it would also be more difficult to acquire such information: One is far less likely to encounter a given tetragram of chords than any single chord, all else being equal. A similar argument bears on an improviser's acquired motor routines. Any given single chord is more likely to be rehearsed than any given sequence of chords, it would likely be more strongly encoded and therefore resistant to change.

This perspective could lead to an additional conjecture about style evolution in general. Style structures with few elements should be more conserved than those with many elements, especially when improvisation is involved, whether this arises from cognitive representations,

perceptual processes, or motor routines. Corpus methods might prove useful to test this conjecture for both music and other cultural constructs.

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