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# An Exploration of the Use of Tempo in Jazz

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Eight- and sixteen-bar segments of a large number of historical jazz recordings were timed with a stopwatch, and summary statistics were calculated from those measurements. A variety of aspects of the control of tempo were analyzed. Tempo is normally distributed when calculated in terms of metronome markings, but not when calculated in terms of durations. Jazz performance is very stable, even for solo performers. However, systematic patterns in the small variability observed indicate that it can serve expressive purposes, as evidenced by positive intercorrelations among alternative versions of the same tunes, as well as other factors. It was also discovered that when the bands execute a rapid "double time," the ratios among the tempo changes deviate systematically from exact doubling. Many of the effects can be summarized by hypothesizing that there are two (and perhaps more) preferred tempo ranges.

JAZZ, like all music, provides a window into many aspects of human cognition, but it is in the rhythmic domain that jazz distinguishes itself, most notably in the hard-to-define characteristic called "swing." Swing undoubtedly has many components, but an important one is the premium simultaneously put on rhythmic rigidity and fluidity. In contrast to many other forms of music, in jazz there is not supposed to be any rubato in the ground beat. It has been asserted that "When one jazzman confides that another "has no beat'—and there is no harsher criticism—he is impugning his metronome sense" (Stearns, 1970). The fluidity of the soloist is predicated on a solid rhythmic foundation; "The polyrhythmic designs of a jazz band depend on the rock-steady maintenance

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of basic rhythmic suggestions on and around the $\frac{4}{4}$ beat. It is the drummer's function to assure this . . ." (Hobson, 1939).

A fair amount of folklore on the nature of jazz rhythm has been generated on the basis of musical intuition. Often, the components of the rhythm section are said to maintain particular rhythmic relationships; one might say that the bassist is "ahead of the beat," "behind the beat," or "right on top of the beat." For example, "it may be pointed out that often in a jazz performance the only instruments playing regularly *on the beat* are, say, the bass drum and string bass; the rest are playing rhythms variously suspended around the beat—as it were, eccentric to it" (Hobson, 1939, p. 49, emphasis in the original). As early as 1925, it was asserted that "Jazzing up a piece is to start (a note) a little ahead of the beat" (Thomson, 1925).

The substantiation of such claims is often left to the ear, which is problematic given the tendency for preconceptions to influence perception. Given that jazz is primarily an improvised music, direct capture of data is essential to understanding it. Although the apparatus exists to capture data more precisely, few efforts have been made to do so (but see Ellis, 1991, and Rose, 1989).

As a prolegomenon to looking at local and subtle aspects of rhythmic performance, we thought it useful to get a picture of the most global aspect of rhythm, tempo. We did so by using a very simple technique—timing segments of recordings with a stopwatch. This technique lacks the reliability of direct computer input of data and gives only general tempo information, rather than beat-by-beat data. Yet it turned out to be reliable and informative, and it allowed us to examine a corpus of historical work that was recorded before the advent of the Musical Instrument Digital Interface (MIDI) and was too large to be studied conveniently by direct digitization. Because so little has been done to study rhythm in jazz, we found that many questions could be approached on the basis of these global tempo data.

Five data sets were collected, the first of which was intended to address a simple question: do jazz musicians prefer particular tempos? Laboratory research on motor control (Collyer, Broadbent, & Church, 1992) has shown a subtle but distinct preference in subjects for specific "signature" tempos, as if each subject had a limited set of oscillators that were entrainable to a variety of tempos, but had preferred or dominant tempos. The signature frequencies of the oscillators differed among subjects, yet there tended to be certain ranges preferred by all subjects. Would tempo preferences be manifested in a naturalistic setting?

Beyond this initial question, it would be interesting to understand the causes of tempo choices, tempo variability, and tempo trends. The four succeeding data sets follow up on questions raised initially.

## General Method

### DATA ACQUISITION

The same method was used in the acquisition of all data, with data sets differing only in the details of what was timed. Two or more segments of each recording were timed. These were usually 8, 12, or 16 measures long, but were occasionally of different lengths when dictated by an unusual song structure. Timing was done by hand by the second author, using a stopwatch with resolution of 1/100 of a second. In order to check the reliability of this method, the timings of 166 durations across 28 different recordings were replicated between two and four times each. The root mean squared deviations of all replications about their respective means was 48.75 ms. This represents quite a small proportion of the total durations timed, as these were in the 10-s range, which is not surprising, because the starting and stopping of the stopwatch was essentially a reaction time to the intervals' beginnings and endings. Consistent with this, the variability in the timing was not affected by the actual duration timed (the Spearman correlation between mean and the standard deviation was .03, NS).

### DESCRIPTION OF THE DATA SETS

The five data sets included a total of 186 tunes or alternatives takes, spanning a broad range of eras (1917–1985) and styles. Choosing a representative sample of jazz recordings is inevitably somewhat arbitrary, but an effort was made to chose equal numbers from the four basic jazz styles generally accepted by jazz scholars, which correspond roughly to four historical periods in the music's development. All groups or individuals chosen were among the leaders in their styles or eras, and many of the dominant players were included. All recordings were in $\frac{4}{4}$ time; performances in $\frac{3}{4}$, "Latin beat" and other modes were omitted. Table 1 gives general information about the data sets, and more information is given in the separate discussions.

Because of the number of recordings examined, it was infeasible to time all segments. Typically, alternating segments were timed, omitting rubato segments, interludes, drum solos, and other segments that tended to be out of tempo or of unusual lengths. An average of about five segments were timed for each recording, a minimum of two separate segments were timed in each recording, and all segments were timed for some performances.

### DATA ANALYSES

The analyses were based on the durations of the timed segments, along with codings of other pertinent information about each recording. How time is to be coded is an issue; psychologists think of time in terms of durations, whereas musicians typically think of the reciprocal durations: beats per minute (metronome markings [MM]). Because of the nonlinear relationship between the two, the choice of representation could be of consequence. For reasons to be discussed, analyses were done by converting segment durations to average MM (except where noted). Also, some ordinal analyses were done for which the choice of representation is irrelevant, as the two are monotonically related.

Three summary statistics of each recording provided the predominant dependent variables. The mean and standard deviation summarized average tempo and variability, respectively. Spearman's rho (rank order correlation) between segment tempos and the order in which they occurred in the song was used as the metric of monotonic tempo trend. This statistic, henceforth referred to as the *trend* for the sake of brevity, is positive when the performance tended to accelerate ("rush," following musicians' parlance) and negative when the tendency was to decelerate ("drag").

TABLE 1

**Summary Information About the Five Data Sets**

| Data Set | Total No. of Tunes[a] | No. of Takes/Tune | Date Range | No. of Artists | Representative Artists | No. of Segments Timed/Recording | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Minimum | Maximum | Mean |
| Bands | 100 | 1 | 1917–1985 | 27 | Louis Armstrong, Sidney Bechet, Sun Ra, Johnny Hodges, Charlie Parker, Wynton Marsalis, Duke Ellington, Jelly Roll Morton, Count Basie, Art Ensemble of Chicago | 3 | 11 | 5.3 |
| Solo piano | 25 | 1 | 1935–1949 | 5 | J.P. Johnson, Dave McKenna, Mel Powell, Jess Stacy, Art Tatum | 2 | 9 | 4.7 |
| Alternate takes | 15 | 2–4 | 1929–1947 | 5 | Johnny Hodges, Coleman Hawkins, Benny Goodman | 4 | 10 | 5.8 |
| Teddy Wilson | 29 | 1–7 | 1934–1941 | 1 | Teddy Wilson | 6 | 24 | 12 |
| Tempo doubling | 17 | 1–3 | 1927–1973 | 9 | Bob Crosby, Eddie Condon, Ben Webster, Louis Armstrong | 2 | 3 | 2.6 |

[a]Includes alternate takes.

## Data Set 1: Bands

Our first concern was to look for general tempo preferences and to see how important style, era, and band size were in determining tempo choices and tempo variability. Accordingly, the recordings covered a broad historical range of jazz periods and styles. The 100 tunes timed were coded for year (ranging from 1917 to 1985); into four stylistic categories: New Orleans ($n$ = 27) swing ($n$ = 31), bebop ($n$ = 30), and avant-garde ($n$ = 12); and into two categories according to the band sizes: big, with typically 12–16 performers ($n$ = 16), and small, with typically 3–8 performers ($n$ = 84). This distinction has further significance in that small band performances were largely improvised, and big band ones were largely arranged.

RESULTS

### Distribution of Mean Tempos

The distribution of mean tempos appears skewed when plotted in terms of minutes per beat (Figure 1A), but it appears more nearly normal when plotted in terms of beats per minute (Figure 1B) and passes a test for normality (Lilliefors test, $p$ = .79). This normal shape provides evidence against our initial hypothesis that tempo choices will show strong clusterings, as no egregious clustering is manifest. Considering the diversity of musicians, styles, and eras represented, perhaps this ought not to be surprising. It is plausible that mean tempos represent the sum of innumerable factors, and the central limit theorem will thereby predict that the ultimate tempo choices would be normally distributed. If this is indeed the source of the normal distribution, this indicates that the factors sum in terms of MM, not duration per beat, consistent with the way that musicians normally think about tempo.

### Global Predictors of Mean Tempo

Average tempos for different styles, band sizes, and eras were all the same. Mean tempos for big bands (MM 182) and small bands (MM 184) were virtually identical [$F(1,98)$ = .14, $p$ = .91]. A similar lack of differences was obtained among styles [$F(3,96)$ = 0.57, $p$ = .64] and when date of recording was used as a predictor of mean tempo ($r$ = .07, $p$ = .48). The only difference among styles was a tendency for the older styles to have a more normally shaped distribution and newer styles to have more uniformly shaped distributions, perhaps owing to the older styles' use as dance musics, which forced them toward middle tempos.

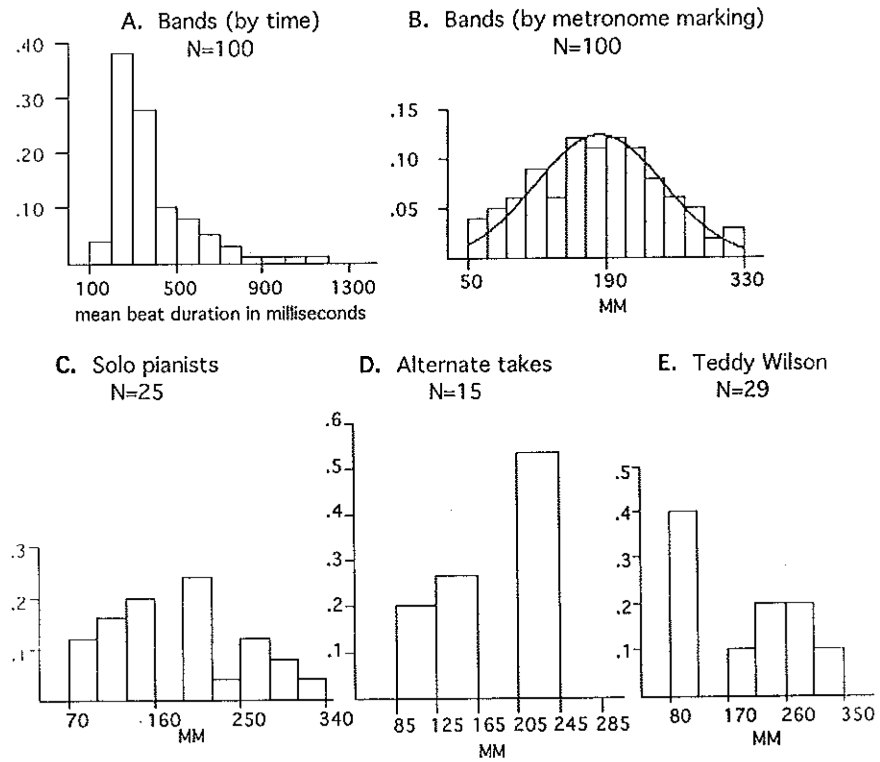


**Fig. 1.** Histograms of distributions of mean tempos for the first four data sets. The first two figures contrast the distribution in terms of the beat durations to the distribution in terms of the metronome marking, which are reciprocally related. The alternate versions of tunes were averaged before diagramming the histogram for Teddy Wilson.

## Within-Tune Variability

Overall temporal stability was high, consistent with the premium put on this by jazz musicians. Coefficients of variation (the standard deviation divided by the mean), using the total timed segments, ranged from 0.01% to 7.00%, with a mean of 1.90%. The stability bespoken by these numbers is also seen in an alternative, conservative index: the range of the metronome markings in each tune expressed as a percentage of the tune's mean tempo. Of the 100 tunes, the largest change in any one was 16%; only 10 of the recordings varied more than 10%, and fully 61 of them varied less than 5%.

Precise comparison of these numbers with similar indices from other domains is difficult, as the fact that these 8-, 12-, and 16-bar segments were subdivided into beats virtually guarantees an increase in accuracy over what could be expected from the raw timing of these durations

(Getty, 1976; Killeen & Weiss, 1987). Variability at the beat level might have been higher. Even so, the data vindicate the belief that jazz is a fairly metronomic music. Because the remainder of this paper explores the sources of the residual variability, it is important to bear in mind how small this variability actually is.

Some variability is accounted for by two global factors. Consistent with virtually all of the psychological literature in diverse domains (i.e., Weber's law), slow songs are more variable than fast songs, because there is more room to vary (Figure 2). Second, style plays a small but significant role, as mean MM standard deviations are smaller for the older styles (New Orleans and swing) than for the newer (bebop and avant-garde), reflected in a significant difference among standard deviations [$F(3,96) = 4.07$, $p < .01$]. In general, later recordings had larger standard deviations but the effect is small ($r$ between date and standard deviation, .22; $p < .05$), and date is confounded with style. Style is probably the more critical of the two variables; again, the earlier styles are more strongly associated with dance, for which stability is important. In general, these effects were small; a regression of the standard deviation on date of recording, style, and band size accounted for only 12% of the variance. Furthermore, differences in variability according to era could be merely due to differences in the lengths of the tunes, because later recordings were often longer, and longer tunes would leave more room for variability.

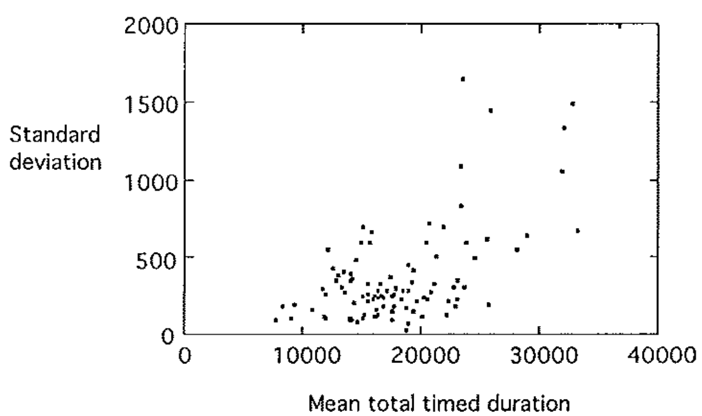


**Fig. 2.** Bands data set: Tempo standard deviations as a function of mean tempos, in milliseconds. The calculations were based on the total durations timed, rather than the metronome tempos. In an exploratory vein, a large number of variants of Weber functions were fit to the data (cf Getty, 1975; Killeen & Weiss, 1987), but none of them yielded good fits; the subdivision of the timed durations into beats by the musicians makes this a tricky enterprise.

## Monotonic Trends

A particular pattern of variability of musical interest is the tendency to consistently speed up or slow down, usually referred to disparagingly by jazz musicians as "rushing" and "dragging." Here tempo trend is assessed by using the Spearman correlation between the segments' positions in the recordings and their tempos. Because of the small numbers of segments timed in each recording, only trend patterns across multiple recordings can be meaningfully evaluated.

There was no general preference between acceleration and deceleration. The mean trend was .02, and the distribution was bimodal (Figure 3A); only 17 of the 100 correlations were between −.3 and .3. Some insight into this preference for change over stability was afforded by an analysis of tempo trend as a function of mean tempo. We originally hypothesized that slow tempos would accelerate and fast tempos would decelerate, because of a tendency to gravitate toward an ostensibly preferred middle "swing" tempo. Belying expectation, tempos frequently diverged away from the mean, slower tempos tending to be associated with deceleration and conversely for faster tempos ($r = .30$, $p < .01$). Splitting the selections into two groups about the mean tempo resulted in mean trends of −.17 for the slow group and .20 for the fast group [$t(99) = -19.7$, $p < .001$]. Even the most extreme tempos did not necessarily tend toward the mean; 6 of the 10 slowest tempos tended to decelerate (mean trend = −.30, nonsignificantly different from 0), whereas 9 of the 10 fastest tempos tended to accelerate (mean trend = .51, $t = 2.77$, $p < .05$ when compared with 0).

However, the tendency of tempos to diverge away from the mean was mild, and cannot explain all of the bimodality of trend, because distributions of the trends of both the slower and faster sets of tempos were also bimodal. It would be tempting to infer that jazz musicians prefer tempo change over stability. This is made dubious by the ability of a random walk model to simulate the bimodal shape of the distribution of the trend correlations (Figure 3D), which incorporated no assumption of a preference for tempo change. Thus, tempo trends might arise adventitiously out of musical structure or other factors.

Finally, style and era were again only weak predictors. The correlation of date with trend indicated that later recordings tended to accelerate whereas earlier ones tended to decelerate ($r = .21$, $p < .05$). Consistent with this, older styles tended to decelerate (mean trend, swing = −.11, New Orleans = −.16) whereas the newer styles tended to accelerate (bebop = .22, avant garde = .30), although the differences among groups failed to reach conventional significance levels [$F(3,96) = 2.39$, $p < .10$]. Stepwise regres-

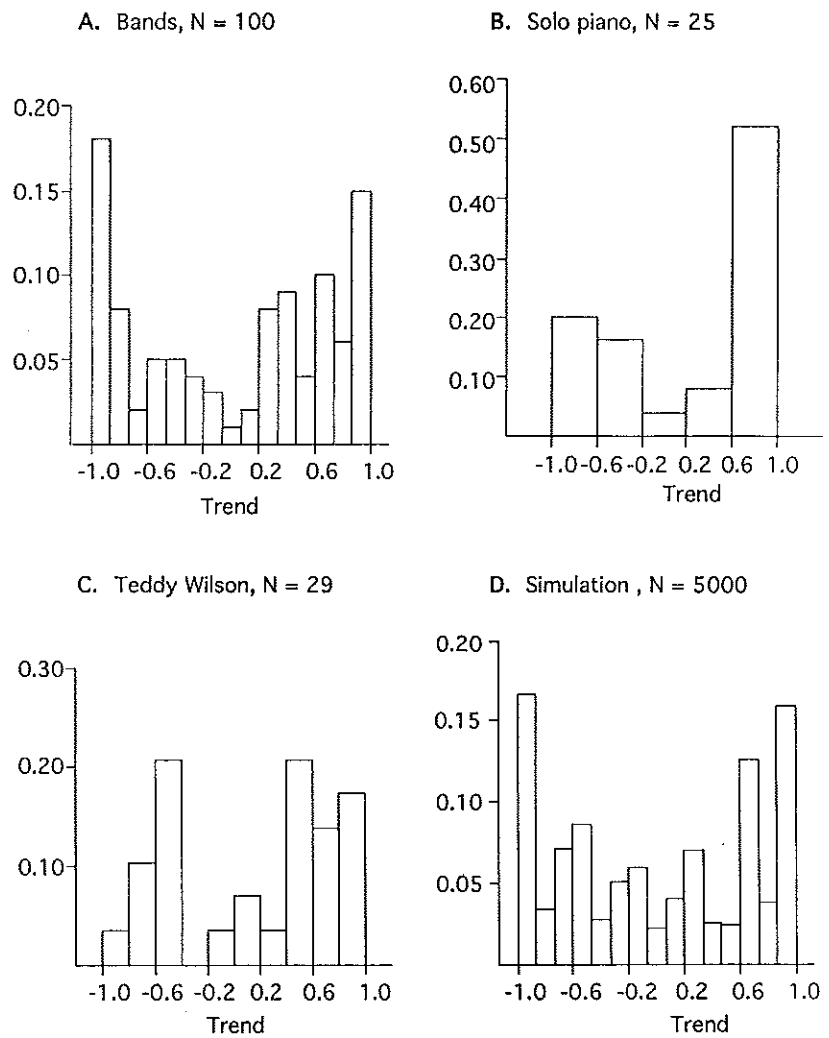


**Fig. 3.** Distributions of the trend coefficients (Spearman's correlations between tempo and position in the song) for three of the data sets (A–C) and a simulation (D), where negative numbers indicate deceleration and positive numbers indicate acceleration. The bimodality observed here was not seen in the "alternate takes" data set, since almost all of the trends were negative. The simulation was based on the assumption that tempo changes derived from a random walk: Duration (N + 1) = Duration (N) + $\varepsilon$, $\varepsilon \sim$ N (0,1). For this simulation, the length of each vector generated was five, about the average number of timings for each recording in the data sets, and there were 5000 trials, each generating a single Spearman correlation with the order vector of {1,2,3,4,5}.

sion of the trends on mean tempo and date showed both variables to be significant, although the variables jointly accounted for only 14% of the variance.

### DISCUSSION

The foregoing analyses provide some insight into tempo in jazz, but the primary conclusion is negative; global factors such as style, era, and band size are not powerful predictors of tempo choice and control. However, it is possible that many of the determinants of tempo exist at a more microscopic, musicological level. Factors idiosyncratic to individual tunes, tune sections, or performers might be important. For example, certain soloists might tend to slow down or speed up, or particular drummers might push songs into preferred tempos regardless of that set by the bandleader. Therefore, further data sets were collected to take more focused looks at tempo.

## Data Set 2: Solo Pianists

The first issue was whether the tempo preferences that did not emerge across a large corpus might emerge when looking at solo performers, in this case pianists. We presume that the tempo settled on by a group of musicians is the result of a complex process, including both the explicit setting of the tempo before the tune is started, as well as an implicit tug of war among the musicians that might adjust the tempo during the performance. Perhaps this interactive process obscures individual musicians' preferences. Furthermore, it would be interesting to know the extent to which tempo stability is due to the group process; do soloists vary the tempo more?

The corpus consisted of 25 solo piano performances; five by J. P. Johnson, nine by Dave McKenna, nine by Art Tatum, and one each by Mel Powell and Jesse Stacy. These players span jazz history. Johnson was originally a ragtime player who grew into jazz as it appeared, Powell and Stacy were among the finest of the swing pianists, Tatum, with an idiosyncratic style initially developed in the swing era, is considered among the piano greats, and McKenna is a modern player.

Tunes or segments of tunes that were sufficiently rubato as to lack a well-defined beat were omitted. Thus, standard deviations are conservative indices of temporal variability.

### RESULTS

The existence of rubato segments in the data argue prima facie that solo pianists took greater liberties with the tempo than the bands did, a fact buttressed by measures of variability of the timed segments. The maximum coefficient of variation was 20%, and the mean was 4.4%, both figures higher than those for the bands' data set. Alternatively, the average of the ranges divided by the means was .10. Comparison of the distribution of this index with that of the bands data set shows the greater variability here; the maximum was 41% (vs. 16% for the bands), 40% were greater than .10 (vs. 10% for the bands), but conversely only 36% were less than .5 (vs. 61% for the bands). The greater liberty taken with the tempo given the absence of band and drummer is only relative, though, as these figures still bespeak a fair amount of stability.

Turning to tempo preferences of all of the pianists together, the mean tempo of MM 182 and the generally normal shape of the distribution (Figure 1C) match what was seen for the previous data, but with one difference; inspection of the tempos used by individual pianists (Table 2, first five pianists) reveals no egregious tempo clustering, yet as a group a curious gap between MM 157 and MM 191 emerges. Furthermore, many of the middling tempos are contributed by one pianist, Dave McKenna. At the same time, we see two tendencies that were present in the bands corpus; bimodality of the distribution of the trends about a mean of .25, and a tendency for tempos to diverge away from the mean, that is, for slow tunes to slow down and fast tunes to speed up (Spearman correlation between tempo means and trends = .25). The latter effect is weak, because only 9 of the 25 trends are negative; but of these, four out of five of the lowest mean tempos are associated with negative trends (mean trend = −.46, compared with .42 for the remaining 20), whereas only 2 of 10 of the fastest tunes have negative trends.

The bimodality of mean tempos raises the possibility that there are tempo preferences, but rather than being for specific tempos, they are for two ranges, a slow and a fast one. The divergence of tempo trends away from the middle is consistent with this.

TABLE 2

**Sorted Mean Tempos for Solo Pianists, Including Teddy Wilson**

| Pianist | Mean Tempos | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| James P. Johnson | 93 | 121 | 134 | 286 | 288 | | | | | |
| Dave McKenna | 77 | 121 | 136 | 143 | 157 | 191 | 194 | 200 | 221 | |
| Mel Powell | 279 | | | | | | | | | |
| Jess Stacy | 192 | | | | | | | | | |
| Art Tatum | 93 | 110 | 111 | 152 | 194 | 212 | 254 | 257 | 335 | |
| Teddy Wilson | 82 | 92 | 92 | 102 | 171 | 217 | 243 | 270 | 289 | 321 |

NOTE. Each metronome tempo represents the average time for one recording, except those for Teddy Wilson, where the numbers include averages of all alternate takes of each song.

## Data Set 3: Alternative Takes

A shortcoming of the analysis of the first data was the lack of attention to the tunes' structures. It is plausible that small section-by-section variations in tempo are used by the performers for expressive purposes. These could be spur-of-the-moment variations, or idiosyncratic to a given song, or commonly used stylistic tricks. The last two cases predict consistency across replications. Many jazz recordings are released with two or more alternate takes of the same song. A consistent schematic representation of each song would lead to positive intercorrelations in the tempo variations across different takes of the same song.

Accordingly, we gathered a data set consisting of six tunes, each with two to four alternate takes, for a total of 15 cuts. Alternate takes were recorded on the same date, except for Benny Goodman's "Roll 'em," for which the alternate takes were separated by a period of several months. These were mostly band performances. The historical breadth of the data set (1929–1947) was limited by greater difficulty in finding sets of alternate takes.

### RESULTS

Turning first to general tempo information, the distribution of mean tempos shows a gap between MM 161 and 205 (Figure 1D), similar to that seen in the preceding data set. Thirteen of the fifteen trend correlations were negative, indicating a general preference for slowing down regardless of base tempo in this corpus. Consequently, neither bimodality of trend was observed, nor a tendency toward divergence (Spearman's correlation between mean tempo and trend = .05).

Scatterplots indicated that alternate takes tended to be monotonically related to each other, but did not share any particular form of dependence, so Spearman's correlation matrices were derived by correlating equivalent segments among the multiple takes. All of the 13 resulting correlations were positive, with a median of .66. Thus, tempo variations across alternate takes do manifest consistency, favoring the hypothesis that jazz artists approach songs with consistent representations.

These intercorrelations are doubtlessly in part due to the tendency for the alternate takes to share similar monotonic trends (mostly slowing down). This source of similarity must be interpreted with caution, because monotonic similarity does not necessarily imply that tempo variation is schematically driven. Rather, very general factors might cause the monotonic patterns, such as the preference to decelerate observed here. Therefore, the presence of nonmonotonic similarity among takes would argue more forcefully that a pattern of tempo changes is part of a tune's expressive structure.

In order to extract this nonmonotonic similarity, the data were detrended by taking first differences, that is, taking the difference between the duration of a segment and the preceding one in the order of the tune (Chatfield, 1989, p. 17). Although not all segments had been timed, all timed segments in alternate takes occurred in analogous positions in the tunes, so that first differencing should have removed trend while leaving similarities among takes due to the tunes' structures (e.g., structural position or choice of soloist). Correlation matrices were recalculated on the differenced data. Although the differencing operation diminished by one the already small numbers of samples that went into each correlation, all but one of the correlations were positive, and the median correlation was .70. Thus, the detrending operation did not eliminate the similarities among takes, suggesting that such similarities are schematic rather than merely due to the general tendency to decelerate.

## Data Set 4: Teddy Wilson

To buttress the results of the preceding two sections, 29 alternate takes of 10 performances by pianist Teddy Wilson were examined, spanning the years 1934–1941. One tune with only one take was included, but the remainder of the tunes included between two and seven alternate takes. Eleven of the takes were with bass and drums, the remainder were unaccompanied. The recordings were timed in their entirety, divided into 8- or 16-bar segments. Teddy Wilson is widely believed to be one of the finest of swing pianists, very influential in his day, and therefore is expected to be a good exemplar of jazz piano playing.

### RESULTS

The mean coefficient of variation (using the total durations timed) was .011 for the selections with bass and drums, which increased only to .014 for the solo selections, and decreased back to .011 after omitting "Liza," the longest and one of the fastest tunes in the collection. Alternatively, the maximum, across the entire Wilson data set, of the tempo ranges divided by their means was .10. Thus, Wilson is virtually as stable when playing alone as when accompanied. This is not because he is a generally variable player, as these numbers compare favorably with the mean coefficient of variation of .019 for the bands' data set. Apparently, stability does not require the presence of bass and drums.

So as to weight each song equally, mean tempos across alternate takes were calculated, and the grand mean and distribution were based on these (Table 2). The grand mean of MM 188 is strikingly similar to those already observed, yet we again see a bimodality of the mean tempos (Figure 1E). There is in fact only one tune with a tempo between 102 and 217, at MM 171 (Table 2, Row 6).

### SCHEMA

As in the preceding data sets, the alternate takes tended to have positive Spearman intercorrelations. The mean correlation of .34 differed significantly from zero [$t$ (44) = 4.97, $p < .001$], and only 9 of the 45 intercorrelations were negative. Intercorrelations were still positive after detrending by first differences and omitting one tune with N = 2, $\bar{X} = .35$, [$t$ (43) = 5.47, $p < .001$]. In fact, only 6 of the 44 differenced correlations were negative. As above, the consistency argues that tempo changes are not merely due to monotonic trend, and therefore are intentional, although perhaps unconscious.

Figure 4 plots trend as a function of mean tempo for all takes of all tunes. The mean trend is .17, but the distribution tends to be bimodal as in earlier cases (Figure 3C). In contrast to some of the earlier cases, there is no divergence of tempo. The correlation between mean tempo and trend is −.32, indicating a tendency for fast tunes to slow down, but when the fastest tune (China Boy) is removed, the correlation is reduced to .07.

The clustering together of alternate takes apparent in Figure 4 indicates that they frequently share similar trends as well as similar tempos. The effect of song on trend, with alternate takes as replications, was significant [$F$(8,19) = 6.19, $p < .005$]. In fact, in the 28 alternate takes, only four

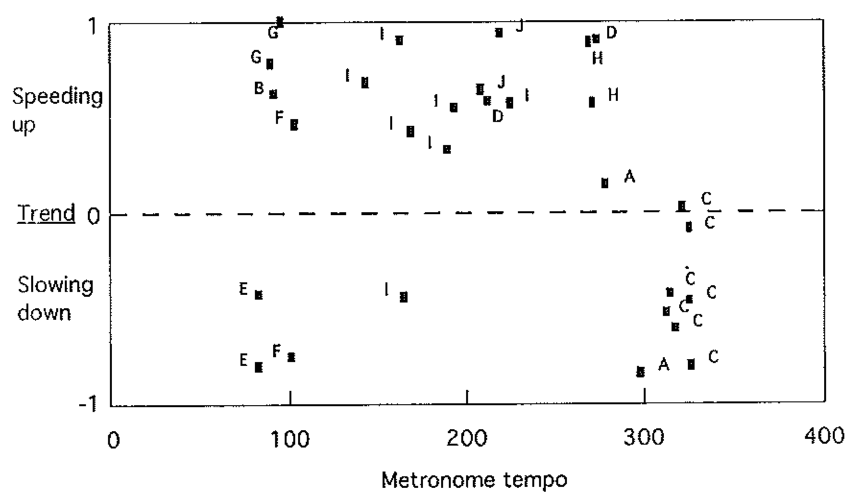


**Fig. 4.** Teddy Wilson: Trend correlations as a function of mean tempo for all tunes, all takes. Positive correlations indicate acceleration; negative, deceleration. Song titles: A = "I Know That You Know," B = "I Surrender Dear," C = "China Boy," D = "Between the Devil and the Deep Blue Sea," E = "Don't Blame Me," F = "These Foolish Things," G = "I Can't Get Started," H = "Liza," I = "Rosetta," J = "Them There Eyes."

correlations were found whose signs did not match the majority of takes of those tunes. Because this consistency is not due to an effect of mean tempo, it is plausible to suppose that it is idiosyncratic to each tune and thus schematic. In other words, Wilson's notion of a given tune includes his preference for accelerating or decelerating it.

Several tempo devices emerged at a level more general than the individual tune. There was a tendency to speed up within the first one or two segments of the tunes. The mean increase was only 1.03 beats per minute, but this was significant [$t(26) = 3.14$, $p < .005$]. Structural aspects of the tunes also determined tempo trends. Aggregating across the tunes with clear AB structures (mostly AABA), the B sections averaged 1.12 beats per minute faster than the A sections [$t(220) = -2.14$, $p < .05$]. This result was also seen in mean difference of 1.23 beats per minute between the B sections and the immediately preceding A sections [$t(63) = 4.21$, $p < .001$]. Clearly, Wilson tends to accelerate while going into the B sections to reinforce the section change, perhaps to increase the excitement, much as a composer uses modulation for similar purposes.

It is instructive to take a closer look at an individual tune, "Rosetta," the only set of alternate versions of a song recorded in different years. A time series plot (Figure 5) reveals the initial acceleration that Wilson seems to like. A second visually apparent fact is that variability within takes is much less than between takes; clearly Wilson was experimenting with

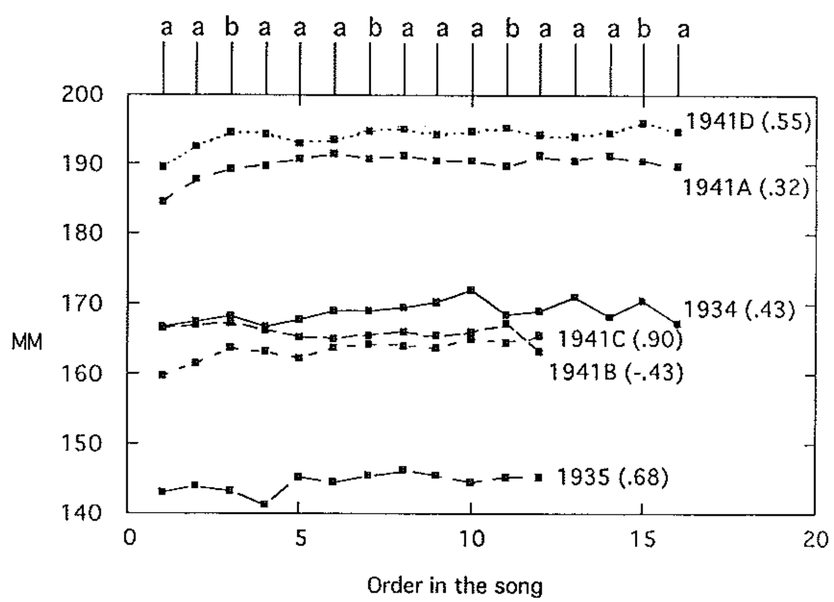


Fig. 5. Time series plot for Teddy Wilson's "Rosetta." The abscissa represents the segments in the order that they occurred, and the ordinate is the tempo. Letters at the top indicate the AABA structure. Note that the slower takes have fewer sections, in order to keep the record length similar. Trend correlations are adjacent to the dates.

different tempos. This is seen in the set of four 1941 takes; assuming that the take orders on the record reflect the order in which they were actually performed (which is usually, although not always, the case), the first and last of these share similar tempos, as do the middle two.

All of the versions are positively intercorrelated except for the second 1941 take, which correlates negatively with everything else. It is interesting to note that the largest correlation (.71) is between the 1934 and 1935 versions. This large correlation exists despite the change of tempo (and consequently, of the number of choruses) between the versions, arguing that the relative tempo changes, hence the tempo schema, can survive a change in absolute tempo changes and an intervening year. Nevertheless, the lower correlations of these versions with the later ones indicate that in 1941 Wilson reapproached the song with a changing conception.

## Data Set 5: Tempo Doubling

A final issue pertains to sudden tempo changes that are often used in jazz, particularly earlier jazz, for dramatic purposes. Bands would frequently effect a rapid change to a much faster or slower tempo for a segment, often followed by a return to the original tempo. The actual ratios among these tempos have not been investigated to this time. To the extent that musicians verbalize their intentions, these tempo shifts are almost invariably referred to as "double time" or "half time" or simply "speeding up"; one virtually never hears a call for a "triple time," for example. If in fact these are the ratios used, this would be consistent with the psychological studies that indicate that simple ratios, of which 2:1 is the paramount example, are rhythmically dominant (Fraisse, 1946, 1956, 1982; Povel, 1981). These preferences typically refer to ratios among notes, not among tempo switches, so whether they intrude in the latter case remained an open question.

The corpus consisted of 18 recordings that contained tempo switches. These switches were typically initiated by a brief solo break, usually by the instrumentalist whose solo followed, who used the break to set the new tempo. Eleven of these (nominally) doubled and then halved, four doubled only, two halved, and one halved and then doubled. Included in these were three tunes each with three alternate takes, these nine cuts allowing us to examine the consistency of the ratios across alternate takes.

### RESULTS

A highly consistent pattern of results contradicting the hypothesis of exact doubling was observed for virtually all of the tunes. All of the ratios of first to second tempos of the 15 "doubling" cases wer greater than 2:1, ranging from 2.11 to 3.73. The mean was 2.68, differing from 2.00 [$t(14) = 4.91, p < .001$].

Curiouser still, in the 11 cases in which there was a nominal return to the original tempo, the third tempo was neither the original tempo, nor the ½ of the doubled tempo, but instead, was between the two. The ratios between the second and third tempos ranged from 2.07 to 2.96, averaging 2.46, significantly different from 2.00 [$t(10) = 4.67, p < .005$]. Finally, the ratio of the first to third tempo ranged from 1.03 to 1.26, averaging 1.11, different from 1.00 [$t(10) = 4.84, p < .005$]. In summary, the musicians more than doubled the tempo and then returned to tempos slightly greater than the initial ones.

Turning to the three cases in which the tempo "halved" rather than "doubled," the ratios of the first to second tempos were 2.59, 1.87, and 2.17. That two of these are greater than 2.00 hints that the preference for ratios greater than two exists regardless of the order of the tempo change, but a larger corpus would be required to confirm this suspicion. The one case with a nominal return to the original tempo presents an intriguing mirror image of the pattern observed in the halve/double cases. The tempo more than halves, and then returns to a tempo slightly less than the initial tempo. The reciprocals of the ratios are similar to the mean ratios in the double/halve cases; 2.59 (first/second) versus 2.68, 2.47 (third/second) versus 2.46, and 1.05 (third/first) versus 1.11.

## ABSOLUTE TEMPO

A complete understanding of the foregoing patterns awaits further research. However, Figure 6 gives a clue about why the ratio of the first to second tempos, in the 15 doubling cases, varied so much: there is virtually no systematic functional relationship between the two tempos (Spearman's rho = −.24, NS). However, the tempo changes are not mere haphazard leaps either, because the alternate takes of the same tune shared similar ratios. There was a significant effect of the tunes on the first-to-second ratio, with alternate takes as replicates (Figure 7) [$F(2,6) = 36.7, p < .001$], with significant effects on the other ratios also present. If the tempo leaps had been haphazard, it would have been impossible to maintain the ratios across different takes, sometimes recorded on different days.

The clustering of alternate takes seen in Figure 6 indicates that much of this ratio consistency was due to consistency of tempo in absolute terms; both initial and second tempos were fairly stable across sessions. Therefore, it probably makes sense to assume that the musicians' memories of the tempos were not in terms of the peculiar ratios, but rather in terms of

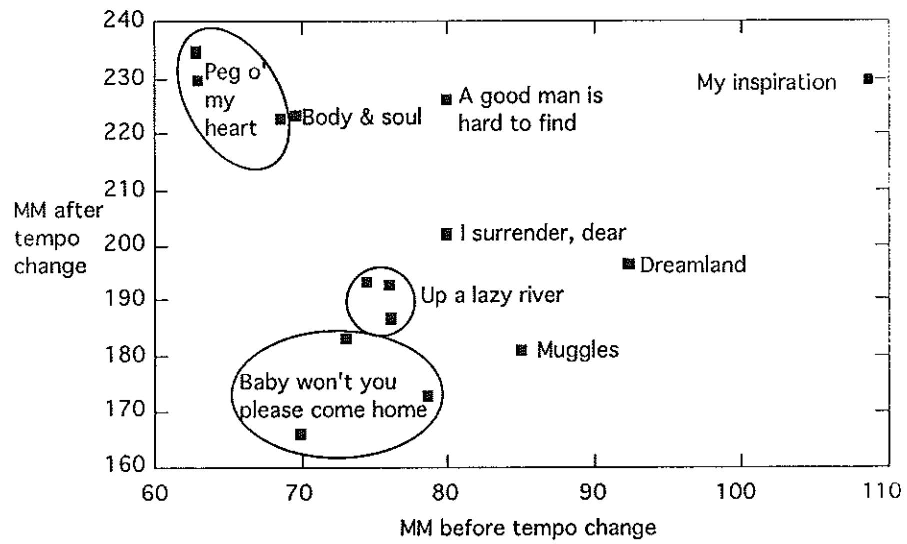


**Fig. 6.** The second tempo as a function of the first for the 15 selections in which a rapid tempo increase was affected ("double time"). Alternate takes of the same tune are encircled.

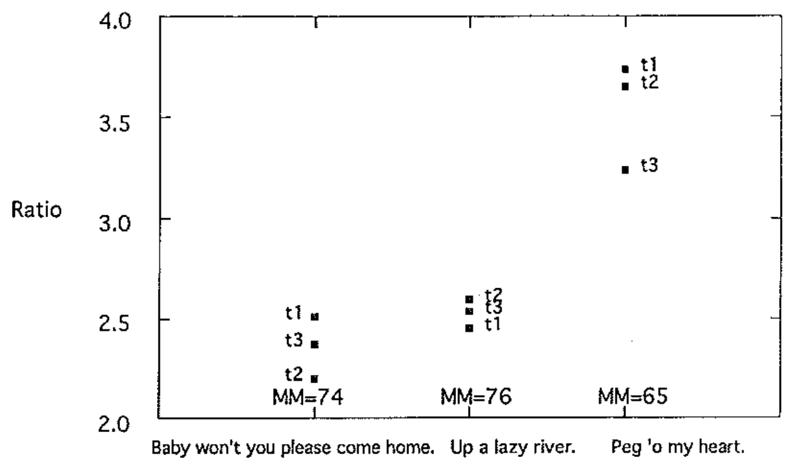


**Fig. 7.** "Doubling" ratio for three tunes with three alternate takes each, illustrating the ratio between the second and first tempos for three takes (t1, t2, t3) of three tunes. Metronome markings give the mean initial tempos. The takes were all in the same sessions, with the exception of take one of "Peg 'O My Heart," which was a live over-the-air broadcast on a different day. The band composition on this take was slightly different from that of the other two takes, in spite of which, the ratio is not discordant with the other two.

the raw tempos. Analogous to absolute pitch, the musicians appear to be displaying a degree of "absolute tempo."

## Discussion

### TEMPO STABILITY

The single most salient fact about jazz rhythm is its stability. In the bands corpus, 65% of the tunes never varied more than 5%. The *largest* values of the range divided by the mean were 16% (bands) 41% (solo pianists), 7% (alternate takes), and 10% (Teddy Wilson). Also, that Teddy Wilson and some of the other soloists were as stable as the groups implies that stability does not require the self-organizing properties of the interaction of multiple participants, but can be generated endogenously by a single performer. We can conclude that the absence of a band allows tempo flexibility, as was seen for some of the solo pianists, but does not necessitate it. That people are capable of rhythmic precision in laboratory settings has long been known, (e.g., Wing & Kristofferson, 1973), but one might have supposed that the complexities of improvising would have made performance more erratic. Although stable tempo is probably neither necessary nor sufficient to define swing, such stability appears to be an important component of the concept. Variation in tempo must be seen as the "icing on the cake" of stability.

### TEMPO VARIABILITY

If stable tempo bespeaks precise temporal control, so too does the fact that some of the remaining tempo variability was sytematic. For the bands data set, style and era were mild predictors of the standard deviation and trend. The positive intercorrelations of the alternate takes, even when detrended, was another piece of evidence, as was the similarity of tempo choices of alternate takes in the "double time" data set. Teddy Wilson's consistency of monotonic trends across takes and his sectionally consistent tempo changes provided still more evidence. The subtlety of these latter techniques is evinced by the fact that the average effects were statistically significant even though they were on the order of one beat per minute, minuscule indeed.

### TEMPO PREFERENCES

An initial hypothesis that triggered this research was that strong clustering of tempo preferences would emerge. The normality of the distribution of the metronome tempos in the first data set, followed by the lack of strong clustering in the other data sets, ran counter to this hypothesis. However, there emerged in the other data sets a tendency for bimodal distributions with gaps roughly in the middle 100's metronome range. The implication is that the middle set of tempos is less favored, as if the musicians have notions of a slow and a fast tempo range. The tug of war over tempos found in band contexts destroys this effect, which is stronger for the solo performers. Congruent with this hypothesis is the trend divergence observed in the bands and solo piano data sets, as this indicated that the musicians moved away from, rather than toward, the grand mean tempo.

There are several reasons why musicians might gravitate toward certain tempo ranges. It could be purely a question of style; either as a facet of jazz style in general or of the styles represented by the piano players who showed this tendency most strongly. Or, it could have to do with stylistic or motoric constraints associated with the piano. A study of a large body of unaccompanied solos by other instruments would address this, although these are unfortunately rarer in the jazz literature.

Alternatively, though, it could be that the preferences are due to the nature of the central timers generating the rhythms. To get some sense of the plausibility of this speculation, the current data were compared with the laboratory data of Collyer et al. (1992). The five subjects in that experiment displayed the ability to tap a continuum of tempos, as in our "bands" data set, but showed a subtle preference for two signature frequencies or tempos. This preference was consistent across sessions separated by months. Collyer et al. (1992) conclude that timing is normally affected by a system that prefers certain "free running" frequencies but is sufficiently flexible to time other frequencies.

To compare the current data with those of Collyer et al. (1992), the first four jazz data sets were split about their respective means, and the means of the upper and lower halves were calculated (Table 3). The preferred rates of the subjects in the study by Collyer et al. were converted to metronome tempos (Table 3). Although the preferred rates vary widely among the five subjects in the laboratory study, their subjects' slow and fast tempos roughly overlap the slow and fast tempos of the jazz data. The grand mean metronome markings are MM 120 (Collyer et al.) and MM 133 (jazz) for the lower tempo, and MM 251 (Collyer et al.) and MM 249 (jazz). There is enough qualitative similarity between the two data sets not to eliminate the possibility that preferences in both are generated by a pair of central timers with slow and fast preferred rates.

The psychological division of the tempos into slow and fast ranges, whether or not this has a central genesis, sheds some light on the mysterious pattern observed for the "doubling" data set. Exact doubling of the initial tempos would have yielded tempos ranging from MM 126 to MM

TABLE 3

**Preferred Tempos from Laboratory Data of Collyer, Broadbent, & Church (1992), Jazz Data Sets, and Analyses of the Concatenated Jazz Data**

| Data | Subject | Slower Tempo | Faster Tempo |
|---|---|---|---|
| Collyer et al. | CC | 90 | 208 |
| | AS | 112 | 282 |
| | JW | 123 | 343 |
| | RC | 130 | 228 |
| | HB | 145 | 192 |
| Mean | | 120 | 251 |
| Jazz data sets, separately | Bands | 130 | 236 |
| | Piano solos | 121 | 239 |
| | Alternate takes | 142 | 228 |
| | Teddy Wilson | 139 | 292 |
| Mean | | 133 | 249 |
| Analysis of preferred tempos for the combined jazz data | | Means analysis | Trend analysis |
| | | 92 | — |
| | | 117 | 117 |
| | | 160 | 157 |
| | | 220 | 230 |

NOTE. The two columns give the lower and upper preferred tempos, except for the combined jazz data, where the columns give the set of preferred tempos derived from the data means and trends, respectively (as described in the text, under "local preferences").

217, with a mean of MM 154. The actual "double" tempos ranged from MM 166 to MM 235, with a mean of MM 203. Thus, true doubling would have resulted in many more tempos in or below the middle range. It is as if the musicians preferred to "leap over" the dividing point between the slow and fast ranges. Landing in the middle range would mean being in the unpreferred area, while landing below it would keep the players in the "slow" range, thus (by hypothesis) not giving a strong sense of a tempo change. Therefore, perhaps this leap into the first range is what "double timing" actually is.

This might explain why the ratios were greater than 2:1, although it would not explain why the ostensible returns to the original tempos were slightly faster than the original tempos. The existence of "absolute tempo" would enable, but not explain, this pattern.

## LOCAL PREFERENCES

The distribution of the first data set was irregular, hinting at the possibility of more than two preferred tempo ranges, more local than the global slow and fast ranges discussed. To explore this, the first four data sets were combined ($N = 169$), and the mean tempos were sorted, differenced, and smoothed, using lag-15 running means as the filter (Figure 8, upper circular points). Minima in this function indicated points of maximum tempo clustering and thus were taken as indices of preferred tempos or "attractors." Minima emerged at MM 92, 117, 160, and 220.

A second approach to the same issue based on tempo trends was performed. This was predicated on the assumption that tempos in the range of an attractor would gravitate toward it. Thus, tunes with mean tempos slightly faster than a neighboring attractor would tend to slow down, tunes that were slightly slower would speed up, and tunes that were "just right" would tend to remain stationary. To test this, we sorted the trend correlations according to their associated mean tempos and smoothed, using the same filter as before (Figure 8, lower points). Following a line of reasoning analogous to that used by Collyer et al. (1992), the negative-going zero crossings of this function were taken to indicate points of indifference or attractors, as these are neither slowing down nor speeding up. Because the minima of the mean function and the negative zero-crossing of the trend function are both indices of attractors, the two functions were predicted to follow each other, but 90° out of phase.

Turning to the data (Figure 8), the extreme points of the two functions tend to go out of the range of the smoothing operation, and the functions tend to diverge at fast tempos. However, in the midrange, both functions appear to follow a roughly triangular waveform, and approximately track

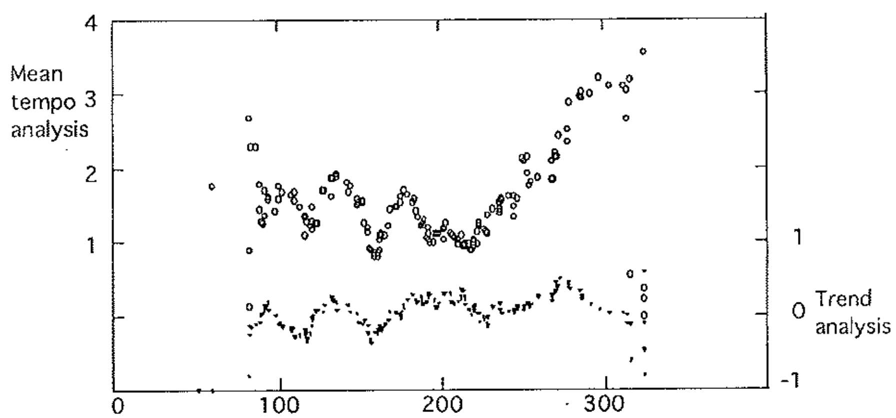


Fig. 8. Preferred tempos estimated by two methods. The circles represent the smoothed first differences of the sorted mean tempos. Here abscissa represents (smoothed) differences between adjacent tempos, in metronome markings, so that minima are points where many selections are clustered in the same tempo area, and thus indicate preferred tempos. The triangles represent the smoothed trend correlations, sorted on the mean tempos. The weakness of the smoothing function at the extremes resulted in some large positive and negative points, which are omitted from the figure.

each other, as is indicated by the Pearson correlation of .56 in the range between MM 90 and MM 190. However, this shows that the two functions seem to be in phase, rather than 90° out of phase, as was initially predicted. It is not clear why this is. In any case, the estimates of the minima of the two functions, gotten by visual inspection of the original data, are in reasonable agreement (Table 3) at about MM 117 (slow), MM 160 (slow-medium swing), and MM 220–230 (up tempo).

### TESTING THE HARDWARE HYPOTHESIS

The foregoing discussion suggests the possibility of two or more preferred tempo ranges, but the claim that these rest on "hardware" rather than stylistic preferences will require further data to become convincing. A number of approaches come to mind, the most obvious being direct observation of musicians' predilections in controlled laboratory settings. Another prediction is that similar tempo preferences will appear across diverse styles. Third, differences in the motor demands enforced by different instruments might alter these preferences (i.e., pianists might have different ideal tempi from bassists), but should not destroy them altogether, if they are indeed centrally generated.

Rhythm is organized hierarchically, and the foregoing assumes that timing preferences are tied to the beat level, which is consistent with models of rhythm that give this level a fundamental priority (e.g., Povel, 1981). This provides another test of the hardware model. Tempo preferences could be compared in situations in which the beat is subdivided differently (e.g., two parts vs. three parts). If preferences are based on the beat, then they will be invariant across beat subdivisions, whereas if they are based on some smaller unit, then they will shift in a predictable manner.

Finally, it is not wholly out of the question that natural activities, such as walking, running, and dancing, are subtly constrained toward preferred frequencies.[1]

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