A microcosm of musical expression. I. Quantitative analysis of pianists' timing in the initial measures of Chopin's Etude in E major

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Patterns of expressive timing were measured in bars 1–5 of 115 commercially recorded performances of Chopin's Etude in E major, op. 10, No. 3. These patterns were subjected to principal components analysis, which suggested at least four independent ''timing strategies'': (1) major ritards at the ends of melodic gestures; (2) acceleration within some of these gestures, without final ritards; (3) extreme lengthening of the initial downbeat; and (4) ritards between as well as within melodic gestures. Strategies 1 and 4 respond in different ways to the melodic-rhythmic grouping structure of the music, and strategy 3 merely represents a local emphasis. Strategy 2 is the one most difficult to rationalize; it does not seem to represent an alternative structural interpretation of the music but rather an alternative gestural shaping. Each individual pianist's timing pattern could be described as a weighted combination of these four strategies plus idiosyncratic variation. A wide variety of combinations was represented, and no two individual patterns were exactly the same. In addition, there was a wide range of basic tempi and of degrees of tempo modulation. There were no strong relationships between any of these variables and sociocultural characteristics of the artists, although some weak trends were observed.
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INTRODUCTION

There is enormous variety in music performance, especially in solo playing where individuality can be given free rein. No two performances of the same work are exactly alike, and this is true even for renditions by the same artist. A musician must exert control over a number of expressive parameters, each of which is continuously variable over time, which results in a combinatorial explosion of possibilities. Yet there are significant constraints on this variety. Infinitely many conceivable performances are never realized because they would be considered bizarre and ''unmusical'' by artists and their audiences. Actual performances thus are only a small subset of the gamut of possible performances. Their variety is hemmed in both by notated instructions (in the Western standard repertoire) and by tacit rules and conventions that define what expressive actions are acceptable, appropriate, and aesthetically pleasing within a given musical structure. Within these constraints (which may vary as a function of style, historical period, and performance tradition), some performances are similar to each other while others are very different; some are conventional or typical (i.e., similar to many others) while others are innovative and original; and some may strike a listener as deficient or crude while others seem sublime.

Judgments about the relative similarity, typicality, and especially the quality of performances are often made by music lovers, critics, or adjudicators on the basis of their auditory impressions, memories, and accumulated knowledge. These judgments may often be very accurate, but they are subject to limits of perception, memory, and attention, and they exhibit considerable individual differences. The goal of objective performance analysis (Seashore, 1936) is to determine the extent to which performances are *actually* similar or typical. (Their quality remains a matter of human aesthetic judgment.) However, even with present-day methods this is a daunting task. Performances not only differ along many dimensions (tempo, timing, dynamics, tone quality, texture, articulation, intonation, etc.) but also vary in most of these dimensions as the music progresses, so that similarity, typicality, and quality change as a function of time: Two performances may be very similar at the beginning but radically different later on, and any single performance may start out conventionally but then continue in a highly original fashion, or it may start brilliantly and then become dull. It would be exceedingly complex and time-consuming to measure and describe all these differences exactly and exhaustively. An objective characterization of performance similarities and differences can be attempted only if the investigation is severely restricted in terms of the length of the music and of the expressive parameters considered. Nevertheless, such a selective analysis can provide interesting information about both general principles and individual strategies underlying expressive performance, information that cannot be obtained easily, if at all, through listening alone.

This study is concerned with acoustic recordings of piano music. This in itself limits the expressive parameters that can be analyzed. Due to its percussive mechanism, the piano only allows expressive variation in timing, dynamics, and articulation. Of these dimensions, horizontal (successive tone onset) timing can be measured with some accuracy in acoustic recordings, but the small intervals involved in vertical timing (the asynchronies among tones in chords) are difficult to recover. Horizontal dynamics (the peak intensities of successive tones or chords) can be measured, but vertical dynamics (the intensities of the individual tones constituting chords) cannot, at least not with existing methods. Articulation (the degree of separation or overlap of successive tones, which includes the effects of pedaling) is extremely difficult to measure, especially where overlap is concerned. Thus a scientific study of acoustic piano recordings is essentially restricted to measurements of horizontal timing and dynamics. Although more complete and more precise measurements could be obtained from recordings made on a MIDI piano, acoustic recordings have the unique advantage of representing the very best artists and a time span of many decades.

Most previous analyses of acoustically recorded keyboard performances (Povel, 1977; Cook, 1987; Repp, 1990, 1992, 1997a, 1997b) were concerned with timing only. Only Gabrielsson (1987) reported dynamic measurements as well. These earlier studies also had relatively small samples of performances. The largest sample, a collection of 28 recordings of Robert Schumann's ''Träumerei,'' was analyzed by Repp (1992). It became clear from that study and from subsequent investigations (Repp, 1997b, and unpublished timing data obtained from 19 performances of Chopin's Polonaise-Fantasy, op. 61) that, with regard to timing at least, there is an inverse relationship between the length of a musical passage and the diversity of individual performances, as measured by correlational statistics. This is so because all artists tend to respond to major structural breaks in the music by slowing their tempo (see Todd, 1985), and the more such structural boundaries there are in a piece of music, the more similar the overall timing patterns of different artists become. However, within a short passage comprising a single phrase, a considerable variety of expressive detail may be observed, presumably because there are fewer and/or weaker structural imperatives at such a local level. If the passage contains structural ambiguities, some of the expressive variety may be due to different interpretations of the detailed musical structure, and in that case performances by different artists may be expected to fall into clusters or categories, each representing a different interpretation. Alternatively or in addition, however, there may be different ways of expressing the same structure, for example, by varying the allocation of emphasis within the passage or by using different temporal or dynamic shapes to give the music a particular character or to create contrast. While some of this expressive variation may be idiosyncratic, distinct expressive strategies shared by several artists can be revealed by statistical analysis of performance measurements. In addition to the primary question of whether such strategies are categorically distinct or form a continuum of expressive possibilities, a secondary question of interest was whether they are related in any way to sociocultural characteristics of the artists, such as their year of birth, nationality, age at the time of performance, or gender.

Such analyses are really informative only when the sample of performances analyzed is as large as possible, so that many different artists and almost all reasonable ways of playing a musical passage are represented. By focusing on the initial measures of a popular composition by Chopin, it was possible to assemble 115 different recordings for the present study. Even though some extant recordings were not included, this was as large a sample as could be obtained from a major archive of recorded piano music, and it seemed sufficient for most analyses attempted here. Only questions concerning correlations with artists' sociocultural characteristics really require a much larger sample to receive conclusive answers, and since such large numbers of recordings, especially from earlier decades of this century, simply do not exist, these analyses will have to remain tentative.

The results of this investigation will be reported in three successive articles. The present article, Part I, deals with expressive timing only. Part II (Repp, submitted) will examine expressive dynamics and the relationship between timing and dynamics. Finally, Part III (Repp, in preparation) will investigate the relationship between the objectively measured expressive patterns and aesthetic evaluations of the performances.

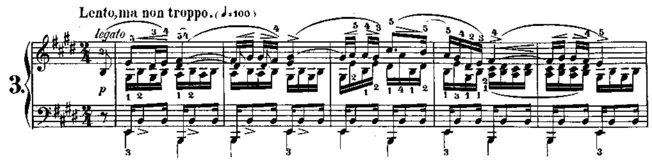

FIG. 1. The initial 5 measures of Chopin's Etude in E major, op. 10, No. 3, copied from the Herrmann Scholtz edition (Leipzig: Peters, 1879).

I. METHOD

A. The music

The musical passage chosen was the beginning of Chopin's Etude in E major, op. 10, No. 3. The score is shown in Fig. 1.[1] The onset of the second beat of bar 5 defines the end of the excerpt as analyzed here.

There were several reasons for selecting this particular passage. First, it represents one of Chopin's most beautiful melodies (the composer himself apparently thought so; see Eigeldinger, 1986, p. 68), which challenges pianists to do it justice and invites large deviations from exact timing in the service of expression. Second, due to the popularity of the Chopin Etudes in general and the E-major Etude in particular, there are many recordings in existence. Third, the passage has a very slow tempo and, apart from the initial eighth-note upbeat, there are note onsets at every sixteenth-note subdivision of the beat, properties that make it convenient to measure and analyze expressive timing. Finally, the same excerpt was employed in a series of recent studies concerned with timing perception and aesthetic judgment (Repp, 1997a, 1998a, 1998b, 1998c, in press). One of them (Repp, 1997a) included an analysis of the timing of 15 performances, which are also included in the present sample. The results of a principal components analysis indicated that there are at least three quite different ways of timing this passage, although the second of these patterns was represented by only three pianists, and the third by only one. These preliminary findings provided the stimulus to investigate a much larger number of recordings in order to determine more precisely the nature and prevalence of these alternative timing patterns.

B. The recordings

To supplement the 15 recordings whose timing measurements were already available (Repp, 1997a), 102 additional excerpts, copied from LPs and CDs onto digital audio tape, were obtained from the International Piano Archives (IPA) at the University of Maryland. The statistical analysis of the timing measurements later revealed that there were two duplicates among the IPA excerpts (see below), so that there were 115 different performances altogether.[2] A complete list of artists' names, record labels, and recording dates is provided in the Appendix. Seven pianists are represented by two recordings each (Arrau, Ashkenazy, Cortot, Cziffra, Egorov, Horowitz, and Slenczynska). Of the 108 artists, 26 (24%) are female. Many nationalities are represented:[3] American (18), Argentinian (2), Australian (5), Austrian (2), Brazilian (2), British (5), Bulgarian (1), Canadian (3), Chilean (3), Chinese (1), Cuban (1), Czech (1), French (12), German (5), Greek (1), Hungarian (9), Italian (3), Japanese (4), Philippine (1), Polish (9), Portuguese (1), Rumanian (1), Russian/Soviet (21), Spanish (2), Turkish (1), and Uruguayan (1). The recording dates span 68 years, from 1927 to 1995.

C. Measurement procedure

The IPA recordings were input as analog signals from the digital tape to a Macintosh 660AV computer, sampled at a rate of 20.055 kHz, and stored as separate files on a hard disk. A digital waveform editor (SOUNDEDIT16) was used to display the waveforms and to locate and mark event onsets, relying on both visual and auditory cues. An ''event'' comprised all tones with nominally simultaneous onsets, so that the excerpt (Fig. 1) contained 38 event onsets delimiting 37 inter-onset intervals (IOIs). In cases of detectable asynchronies within an event, the onset of the highest tone was marked.[4] Naturally, there was some measurement error, but it was considered negligible for the purposes of this study.

Inter-onset interval durations (in milliseconds) were obtained by calculating the differences between successive event onset times. For reasons explained below, the initial upbeat IOI (corresponding to an eighth-note interval in the score) was analyzed separately from the subsequent sixteenth-note IOIs. Those 36 IOIs constituted the timing pattern or timing profile of a performance. Since these IOIs were all nominally equal, the within-performance variation in IOI duration was almost entirely due to intended tempo modulations in the service of expression. (However, a small part of the observed variability must have been due to measurement error and pianists' limits of motor control.) Throughout this article, expressive timing will be depicted and discussed in terms of IOI durations rather than in terms of local tempo (reciprocals of IOI durations, an alternative preferred by some authors).

D. Principal components analysis

To determine how many truly different types of timing pattern were represented in the sample, the 117 timing profiles were subjected to principal components analysis (PCA). This technique decomposes the many individual timing profiles, which exhibit various degrees of pairwise similarity, into a small number of completely unrelated profiles (the principal components or PCs) and associated weights, so that each individual timing profile can be approximated by a weighted sum of the PCs. Each PC may be considered an independent ''timing strategy.'' The IOI durations are converted into standard scores (mean of zero, standard deviation of one) before analysis, and the PC profiles are likewise expressed in terms of standard scores.

The PCs are determined automatically such that the first PC accounts for the largest amount of variance among the timing profiles, the second PC for the largest amount of the remaining variance, and so on. The first PC is in fact equivalent to the average of all the timing profiles, the second PC is the average of the residuals (after the first PC has been subtracted from the data), and so on. The data can be uniquely and exhaustively described by **m** PCs where **m** is the smaller dimension of the data matrix (36 in the present case). If the individual timing profiles were all quite different from each other, then each of the 36 PCs would account for about 1/36 (2.8%) of the variance. However, if there are significant commonalities among the timing profiles, the first few PCs will account for most of the variance. These PCs may then be considered ''significant,'' and the remaining unexplained variance may be attributed to individual artists' idiosyncrasies and noise in the data. To decide how many PCs are significant, the investigator will first look for a clear discontinuity in a plot of the amounts of variance accounted for by successive PCs. If no such discontinuity is evident, those PCs are usually considered significant that account for more than 1/**m** of the variance (2.8% in the present case). The interpretability of the PCs may also play a role in the decision.

If all timing profiles are highly similar to each other, only a single significant PC will emerge, indicating that there is one basic timing pattern, with the remaining variance being due to idiosyncratic deviations from this standard. However, if the data represent several different types of timing profiles, this will result in the emergence of several significant PCs. In that case, a Varimax rotation often facilitates interpretation of the PCs. This rotation modifies the original PCs in order to maximize the number of timing profiles that are similar to a particular PC (''pure'' cases) and simultaneously minimize the number of those that are equally similar to several PCs (''mixed'' cases). The correlation of an individual timing profile with a PC profile is called its ''loading'' on that PC.

II. RESULTS AND DISCUSSION

A. Three aspects of expressive timing

The sequence of IOIs that constitutes a timing profile subsumes three largely independent aspects of expressive timing. The first of these is the average duration of the IOIs, which is inversely related to the *basic tempo*. In performances with highly modulated tempo, such as the present ones, the reciprocal of the average IOI is not necessarily the best estimate of the basic tempo (see below, but also Repp, 1994b), but it probably reflects differences in basic tempo among performances quite accurately. The second aspect of timing is the within-performance variability of the (nominally equal) IOI durations, as measured by their standard deviation. The standard deviation will tend to increase with the average IOI duration (see below), but the ratio of these two magnitudes (the coefficient of variation, a measure of *relative modulation depth*) may be more nearly independent of basic tempo (though see Desain and Honing, 1994; Repp, 1994a, 1995b). The third aspect, which is of greatest interest here, is the pattern of IOI durations or the *profile shape*. The PCA is insensitive to differences in basic tempo and relative modulation depth because it converts the IOI durations to standard scores; thus it deals with differences in profile shape only. Similarly, the correlation between two profiles represents only the similarity in profile shape. Therefore, basic tempo and relative modulation depth as well as the timing of the initial upbeat will be considered separately before the PCA of the timing profiles is discussed.

B. Basic tempo

In an earlier empirical study on the problem of estimating the basic tempo of an expressively timed performance, Repp (1994b) found that musically trained listeners' metronome settings matched the reciprocal of the average IOI. However, this result was obtained with performances of a single musical excerpt (the initial 8 measures of Schumann's ''Träumerei''), and its generality is uncertain. In the case of the present excerpt, there were reasons to believe that the basic tempo is underestimated by the reciprocal of the average IOI (see below; also Repp, 1998c). Therefore two alternative estimates were considered as well.[5] One was based on the median rather than the mean IOI, in order to reduce the influence of very long IOIs. (The distribution of IOI durations was skewed to the left.) The other estimate was based on the average duration of eight IOIs (the sixth and seventh IOIs in bars 1–4) that, typically, were the shortest IOIs in a performance. They all represent the timing of the accompaniment during sustained melody tones and thus provide a measure of the baseline (or maximal) tempo. The initial eighth-note upbeat IOI was excluded from all estimates. Each tempo estimate (expressed in quarter-note beats per minute) was obtained by dividing 15 000 (the number of milliseconds in a minute divided by the number of sixteenth notes in a quarter note) by the relevant IOI parameter (mean, median, or minimal mean). Frequency histograms of the three kinds of tempo estimate for the 117 performances are shown in Fig. 2.

As expected, the median-based method yielded slightly higher estimates than the mean-based method, indicating that the within-performance distributions of IOI durations were skewed towards short values. Baseline tempo estimates naturally were even faster. For all estimates, however, the distribution of tempi in the performance sample was roughly normal, despite one abnormally fast performance (Varsi). Deviations from normality (Kolmogorov–Smirnov test, Lilliefors option) were nonsignificant in all three cases. Tempi were most often between 25 and 32 (mean), 27 and 34 (median), or 31 and 38 (baseline) beats per minute.[6] It is noteworthy that these tempi are much slower than the tempo indication found in most Chopin editions, which is 100

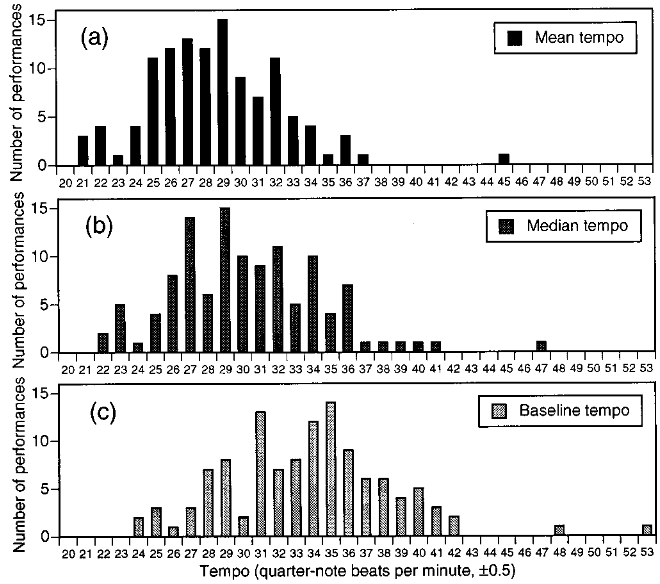

FIG. 2. Frequency distributions of (a) mean tempi, (b) median tempi, and (c) baseline tempi of the 117 performances.

eighth notes (or 50 quarter notes) per minute. (The tempo indication in the German edition shown in Fig. 1 is twice as fast and must be a printer's error.) The fastest performances, after Varsi's, were those by Haase, Renard, Fou Ts'ong, Horowitz-1972, and Paderewski, whereas the slowest ones were those by Katz, Kyriakou, Niedzielski, Pokorna, Goldsand, and Zarankin. The median tempi of all performances are listed in the Appendix.

C. Relative modulation depth

As a measure of absolute modulation depth, the standard deviation of the sixteenth-note IOIs was calculated for each performance. As expected, there was a significant correlation between the average IOI duration and the IOI standard deviation of individual performances ($r=0.43$, $p<0.001$): The absolute magnitude of the timing variation tended to be larger in slow performances. Therefore a measure of relative modulation depth, the coefficient of variation, was calculated for each performance by dividing the standard deviation by the mean IOI. These coefficients did not vary significantly with the mean IOI ($r=-0.17$, $p<0.10$), although the negative correlation almost reached significance, suggesting a slight compression of relative modulation depth at slow tempi, perhaps due to an aesthetic upper limit on the absolute magnitude of timing modulations. The coefficients of variation of the 115 performances ranged from 0.1 to 0.3. The most strongly modulated performances were those by Fou Ts'ong, Pennario, Koyama, Licad, Horowitz-1972, Crown, Sauer, and Koczalski, whereas the least modulated ones were those by Anievas, Székely, Penneys, Murdoch, Duchâble, Iturbi, Egorov-1979, Lortie, Solomon, and Magaloff.

D. The initial upbeat

The initial eighth-note upbeat was excluded from the PCA because its long duration would have had a disproportionate influence on the correlations among the timing pro-

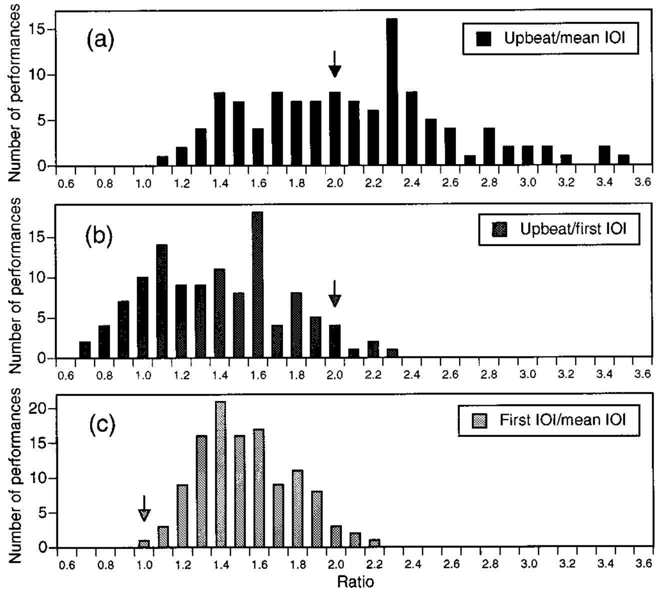

FIG. 3. Frequency distributions of three ratios: (a) upbeat IOI divided by mean sixteenth-note IOI, (b) upbeat IOI divided by first sixteenth-note IOI, (c) first sixteenth-note IOI divided by mean sixteenth-note IOI. Arrows indicate nominal (score-based) ratios.

files. Although this problem could have been circumvented by dividing the upbeat IOI duration in half, there was also enormous individual variation in the duration of this IOI, and quite a few pianists played such a short upbeat as to suggest a sixteenth rather than an eighth note. If some of them actually intended to play a sixteenth note (for whatever reason), division by two would have been inappropriate. Since the pianists' intentions were not known, it seemed best to analyze the upbeat IOI separately.

Not surprisingly, the duration of the upbeat IOI covaried with the average duration of the following 36 sixteenth-note IOIs ($r = 0.59$, $p < 0.001$). This means that the upbeat duration was not independent of the basic tempo of a performance. A frequency histogram of the ratios between upbeat duration and mean IOI duration is presented in Fig. 3(a). The nominal ratio (arrow) was 2, assuming the upbeat was intended as an eighth note. The most frequently observed ratio was a little higher, 2.3, but the range of values was very wide, extending from 1.1 to 3.5. The ratios at the low end of the distribution, with a small peak at 1.4, could be understood as representing sixteenth-note upbeats. (This is what they sounded like to the author.) However, the broad distribution did not deviate significantly from normality.

The upbeat duration may also be considered in relation to the duration of the sixteenth-note IOI on the immediately following downbeat (the "first IOI"). Figure 3(b) shows the distribution of the ratios between these two quantities. Here the nominal ratio was 2 also, but nearly all values were smaller, with quite a few falling below 1, the nominal ratio of two sixteenth notes. This was due to the fact that the first IOI tended to be lengthened considerably in relation to the mean IOI. The distribution of a third ratio, the first IOI divided by the mean IOI, is shown in Fig. 3(c). Here the nominal ratio is 1, but the peak of the distribution is at 1.4, with a range from 1.0 to 2.2. Clearly, the upbeat IOI, although it was often lengthened relative to the mean IOI [Fig. 3(a)], was not lengthened as much or as consistently as the first IOI [Fig. 3(c)]. Therefore the peak at a ratio of 1.6 in Fig. 3(b) may be considered representative of pianists' intention to play the upbeat as an eighth note. However, the values at and below the smaller secondary peak at 1.1 (the deviation from normality approached significance, $p < 0.07$) suggest that some pianists treated the upbeat intentionally or effectively as a sixteenth note. The artists most representative of this strategy were Varsi, Koczalski, Cziffra-1954, Larrocha, Novaes, Janis, Haase, and Hesse-Bukowska. (Note that five of them are female.) Pianists at the other extreme, who tended to play very elongated upbeats, included Vásáry, Katz, Volondat, Wild, Timofeyeva, Ashkenazy-1974, Magaloff, and Arrau-1930 (only one of whom is female). Gender differences will be discussed in a later section.

E. The grand average timing profile

The timing profiles without the initial upbeat, representing a 117×36 data matrix, were subjected to PCA. The first PC accounted for 61.4% of the variance, which indicated considerable commonality among the performances but left room for alternative patterns. The following six PCs accounted only for 6.2%, 4.5%, 3.7%, 2.8%, 2.5%, and 2.2% of the variance, respectively. There was no clear discontinuity in this series, but the second, third, and fourth PCs exceeded the significance criterion of 2.8% (explained above) and the fifth matched it precisely. Therefore a four- or five-component solution seemed appropriate. Both solutions were compared after Varimax rotation and were found to be quite similar: The first four rotated PCs correlated 0.94, 0.99, 0.98, and 0.92, respectively, between the two solutions. Since the fifth PC was not strongly representative of any individual performances, the four-component solution was preferred. It accounted for 75.9% of the variance in the data. The remaining 24.1% were thus considered unexplained and represented a combination of artists' idiosyncratic intentions, lack of timing control, and measurement error.

The first unrotated PC (UPC-I) represents the average of all timing profiles in standardized form. This grand average profile is shown in Fig. 4. A simplified, computer-generated musical score is shown above the graph for guidance. (The second half of bar 5 has been replaced with a chord, to save space.) Filled circles represent IOIs initiated by melody (soprano) tones, whereas open circles represent IOIs initiated by accompaniment (mezzo/alto) tones during sustained melody tones. In this excerpt, all expressive timing may be considered as lengthening relative to a baseline defined by the IOIs in positions 6 and 7 in each bar, which were used to estimate the baseline tempo [Fig. 2(c)]: These IOIs are the shortest and fall almost on a straight horizontal line in the grand average profile. Regarded in this way, the UPC-I profile represents the average magnitudes of various lengthening tendencies in the sample of performances. The initial downbeat in bar 1 clearly was elongated most. The melody is divided into five or six gestures (or segments, or rhythmic groups, the connected filled circles in Fig. 4), each ending with the onset of a long note that also coincides with a change in harmony. A ritard can be seen at the end of each of these

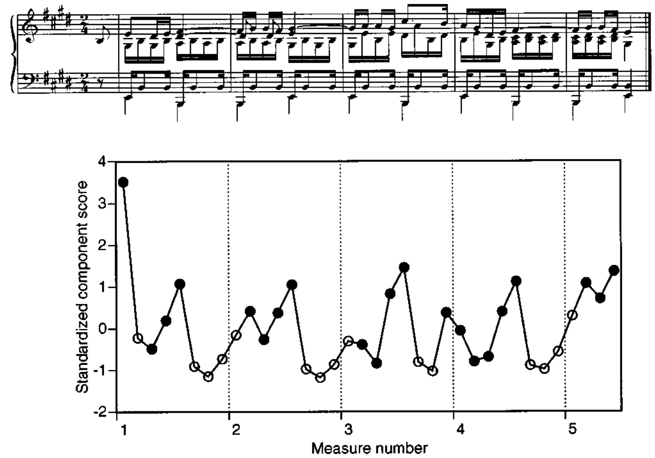

FIG. 4. Standardized grand average timing profile (first unrotated principal component scores, UPC-I). The musical score (without slurs and expression marks, and with a chord substituted for the second half of bar 5) is shown above for guidance. Filled circles represent IOIs initiated by melody tones, open circles IOIs initiated by accompaniment tones.

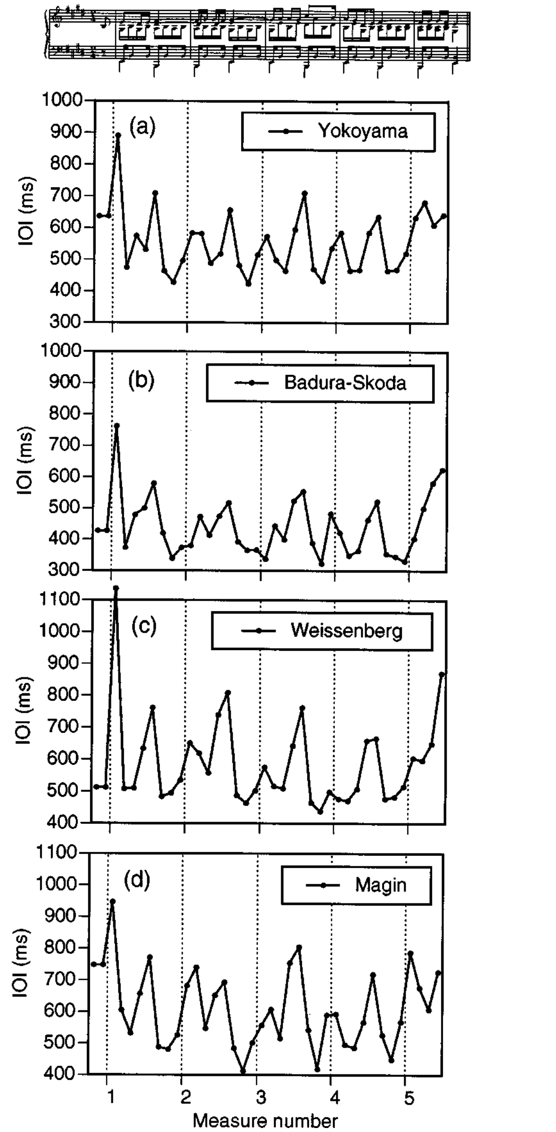

FIG. 5. Four individual timing profiles that correlated highly with the grand average profile (Fig. 4). Initial upbeats are included but shown as two successive sixteenth-note IOIs.

segments, in sixteenth-note positions 4 and 5 of each bar. (It is doubtful whether the initial two melody notes, upbeat and first downbeat, should be considered a separate gesture, but the great lengthening of the initial downbeat is consistent with such an interpretation.) The melodic segment in bar 4 starts earlier than the others (in position 8 of bar 3) and begins with an acceleration; a small initial lengthening can also be seen in other melodic gestures. Finally, there is also a tendency towards ritards in the accompaniment preceding melodic segments, on the first downbeats of bars 2, 3, and especially 5.

These lengthening tendencies clearly articulate the musical structure, most obviously the melodic segmentation and the alternation of melody and accompaniment, though harmonic change and meter may also play a role. The lingering in position 4 in each bar represents the commonly observed strategy of group-final lengthening (e.g., Povel, 1977; Todd, 1985; Repp, 1992), although it could also be understood as a delay preceding a harmonic change. The slightly greater lingering in position 5 may still be part of a group-final ritard, but it also serves to segregate the temporarily suspended melody from the continuing accompaniment, and it may further be due to the metrical strength of the position. The lengthening of the last IOI in bar 3 could represent group-initial lengthening, or an attempt to maintain continuity with the preceding melodic gesture (which culminates in the melodic peak), or a delay before a harmonic change, or even a momentary dwelling on the note that resolves the dissonance at the melodic peak. The ritards in the accompaniment may prepare the entry of a melodic gesture or segregate the accompaniment from the melody, but they also coincide with a metrically strong position. Thus, even though melodic grouping alone can explain most of the lengthening tendencies in this excerpt, it is more likely that they are a complex function of all structural features of the music.

The question now arises whether the UPC-I pattern is at all representative of individual performances, or whether it is merely a meaningless statistical conglomerate. Repp (1997a) has argued that the average timing profile of a large number of performances should be regarded as typical and has shown that performances of student and amateur pianists tend to exhibit timing profiles that are highly similar to the grand average profile. The correlations of the present 115 individual timing profiles with the grand average profile (their UPC-I loadings) ranged from 0.94 to 0.31, with only 22 values falling below 0.70, which shows that most performances were fairly similar to the average, and some were highly similar. UPC-I thus may indeed be regarded as a common, typical, or conventional timing profile for this music, and the UPC-I loadings may be interpreted as indices of the typicality (or conventionality) of individual timing profiles. By this criterion, the most conventionally timed performances ($r > 0.9$) were those of Yokoyama, Badura-Skoda, Weissenberg, Magin, Pennario, Solomon, and Kilényi. (This is by no means a value judgment; for aesthetic evaluations, see Part III of this study.) The timing profiles of the first four of these pianists are shown in Fig. 5. The initial eighth-note upbeat durations have been included in these profiles, but for

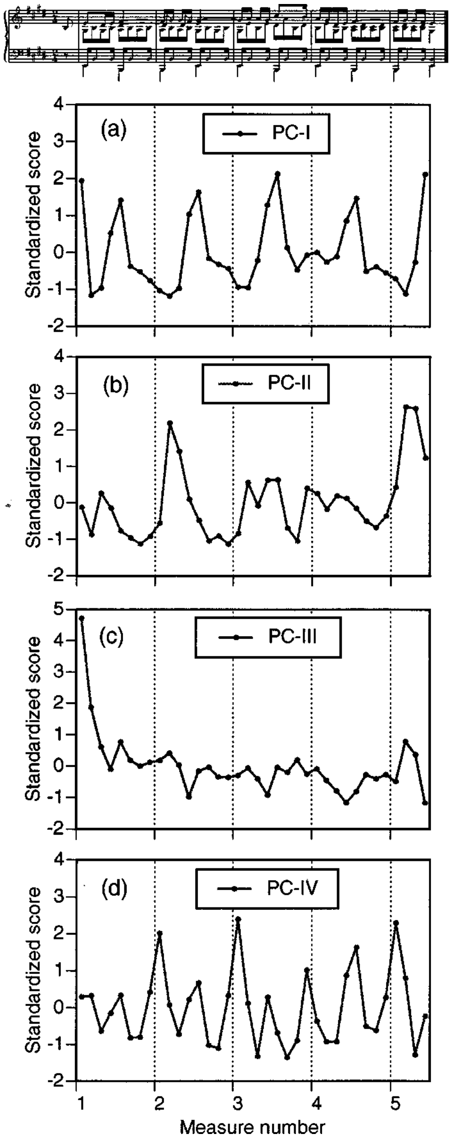

FIG. 6. Standardized scores of the first four rotated principal components.

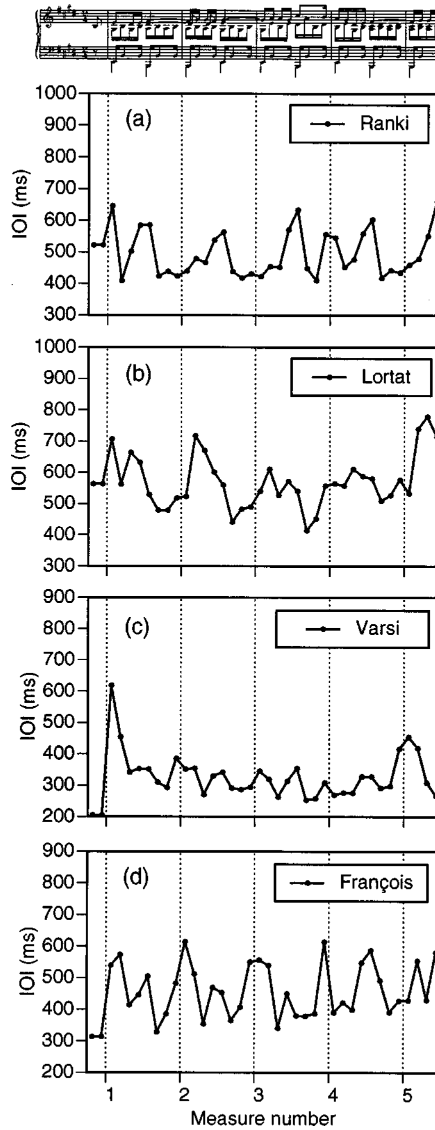

FIG. 7. Individual timing profiles that correlated highly with each of the PC profiles shown in Fig. 6.

graphical reasons they are shown as two successive sixteenth-note IOIs (whose sum constitutes the upbeat duration). The shape similarity of the four profiles to the average profile in Fig. 4 is indeed striking, and they are also fairly similar to each other, though by no means identical: There are individual differences in detail as well as in tempo and modulation depth (which, as pointed out earlier, do not affect correlations). The reader is invited to regard these profiles simply as visual patterns, as it is difficult to ''auralize'' them accurately. It also should be kept in mind that it is the sound that is paced by the timing, and the graphs reveal nothing about the sound (expressive dynamics, texture, etc.) of individual performances.

The most atypical or unconventional timing profiles ($r < 0.6$) were produced by Anda, Horowitz-1972, François, Cortot-1942, Cziffra-1981, Vásáry, Backhaus, Lortat, and Perlemuter; several of them will be presented in later figures. Several of these artists are indeed renowned for their individuality or even eccentricity, and it is interesting to see these reputations supported by objective analysis of such a short musical excerpt.

F. The rotated principal component profiles

To learn more about the different timing strategies of the artists in the sample, the Varimax-rotated PCs were examined. The four rotated PCs accounted for 31.3%, 17.1%, 16.5%, and 11% of the variance, respectively. Rotation does not guarantee the interpretability of the PCs or establish their psychological reality as independent timing strategies; this is a matter of theoretical conjecture and plausibility, as well as perhaps further empirical research. Also, the mathematical constraints of the rotation may introduce some distortions in the shapes of the PC profiles, so it is good to view real timing profiles alongside the statistically extracted ones. The four rotated PC profiles (referred to in the following as PC-I, PC-II, PC-III, and PC-IV) are plotted in Fig. 6, and timing profiles of individual performances loading highly on each

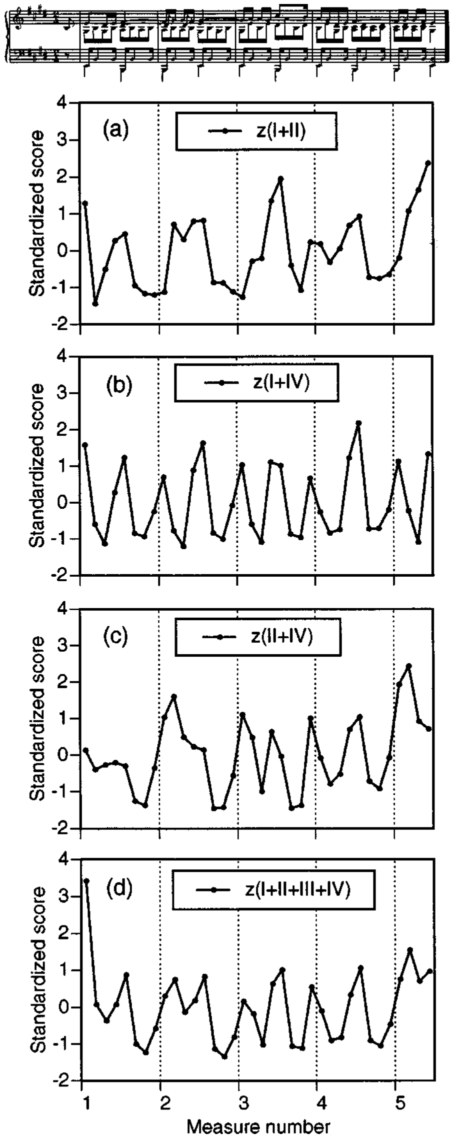

FIG. 8. Standardized scores of some equally weighted combinations of the four PCs.

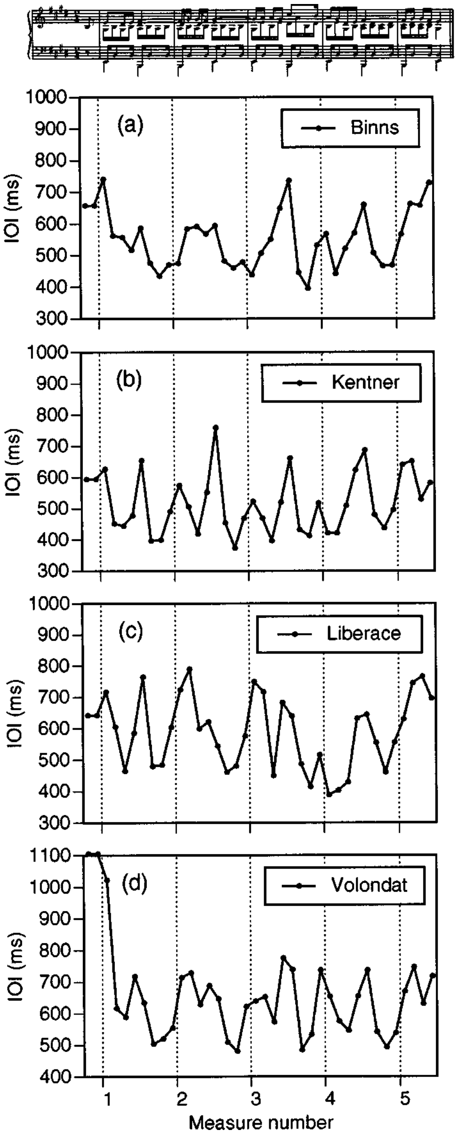

FIG. 9. Four ''hybrid'' timing profiles that correlated about equally with each of the PCs whose combinations are shown in Fig. 8.

PC are shown in Fig. 7. The PC loadings of all performances may be found in the Appendix.

PC-I [Fig. 6(a)] represents the most frequently employed timing strategy. It retains a significant similarity to UPC-I ($r=0.68$, $p<0.001$) and differs mainly in that it emphasizes within-segment ritards but de-emphasizes between-segment ritards and also the segment-initial lengthening at the end of bar 3, which show up strongly in PC-IV instead [Fig. 6(d)]. PC-I also has a long initial downbeat and a ritard during the final melodic gesture. The strategy it represents is mainly one of slowing down at the ends of melodic groups, though the lengthening in the fifth position of each bar may also reflect metrical strength and/or segregation of melody and accompaniment. Loadings on PC-I, which ranged from 0.85 to -0.19, may be considered an alternative measure of typicality. Whereas UPC-I loadings expressed the degree to which a performance represents the *most typical mixture* of timing strategies, PC-I loadings express the degree to which a performance exhibits the *single most common* timing strategy. In terms of this measure, the most typically timed performance was that by Ranki [Fig. 7(a)]. Others who loaded highly on PC-I were Larrocha [see Fig. 11(c) below], Licad, Goldsand, Berezovsky, Hobson, and Mamikonian [see Fig. 11(b) below]. Their timing will be referred to as ''Type I'' in the following. The least typical performances, whose timing was most dissimilar from PC-I, were those by Anda, Cortot-1942, Perlemuter, François, Backhaus, Lortat, and Varsi, largely the same as in terms of UPC-I loadings.

The timing strategy represented by PC-II [Fig. 6(b)] is very different. It dwells on the beginnings of melodic segments, especially in bars 2 and 5, and it completely suppresses the ritards at the ends of melodic gestures. There is no lengthening of the initial downbeat either. In bars 1 and 2 (and probably 5 as well), the pace accelerates during the melodic gesture and continues smoothly into the accompaniment. In bars 3 and 4, the melodic timing is fairly steady, but the two accompaniment notes in bar 3 (positions 6 and 7) are taken very fast. There were quite a few timing profiles that resembled PC-II, with loadings as high as 0.84. The pianist most representative of this ''Type II'' pattern was Lortat [Fig. 7(b)]. Other high loadings were exhibited by Cortot-1942, Goodman, Magaloff, Pollini, Biret, Slenczynska-1956, Iturbi, Joyce, and Cortot-1933. In an earlier PCA of 28 performances of Schumann's ''Träumerei'' (Repp, 1992), a local timing pattern was identified that was virtually unique to Cortot. The present PC-II strategy seems to be associated with Cortot as well, and it is possible that some of the other pianists were influenced by the example of this highly individual artist.

The timing profile associated with PC-III [Fig. 6(c)] has a single salient feature, the extreme lengthening of the initial downbeat, and is almost flat elsewhere, with a small tendency to shorten the fourth IOI in each bar. Nevertheless, a group of performances showed loadings on PC-III as high as 0.79. These ''Type III'' pianists included Backhaus, Kyriakou, Varsi, Yamazaki, Smith, and Monique Haas. It should be noted that a high correlation can result from a single very large value shared by two data sets. For example, Backhaus's timing profile showed substantial timing modulations which, however, were overshadowed by a greatly elongated initial downbeat. Therefore Fig. 7(c) shows Varsi's profile instead, which does exhibit the relative lack of timing modulation suggested by PC-III, though this is due in part to her very fast tempo.[7] (Note also her very short initial upbeat, a good example of a ''sixteenth-note upbeat.'')

The timing profile associated with PC-IV [Fig. 6(d)] is rapidly and systematically modulated. It shows strong ritards in the accompaniment preceding the onsets of melodic gestures (position 1 in bars 2, 3, and 5), as well as smaller ritards at the ends of segments, as in PC-I. There is no lengthening of the initial downbeat and no final ritard, but a lengthening in position 8 of bar 3, which is inconsistent with the purely metrical explanation that this timing pattern seems to invite. An interpretation in terms of grouping is therefore preferred. Loadings on PC-IV reached only a maximum of 0.72; thus there were no very pure instances of ''Type IV'' performances. Those with loadings above 0.5 included Lortie, François, Székely, Vásáry, Katz, Bingham, Kentner [see Fig. 9(b)], Egorov-1978, Perlemuter, Penneys, and Liberace [see Fig. 9(c)]. Figure 7(d) shows the profile of François who, like Varsi, played an extremely short initial upbeat, suggestive of a (lengthened) sixteenth note.

Although the Varimax rotation maximized the number of performances that closely resembled one or another PC, there were many profiles that loaded nearly equally on two or more PCs. In theory, this could result either from the combination or the alternation of timing strategies, though the following examples suggest that combination is more likely or at least more frequent. Combinations of the Type III strategy with the others are not of great interest because Type III represents only a single salient feature (lengthening of the initial upbeat). Figure 8 shows what the timing profiles of equally weighted combinations of pairs of the other three strategies would look like, as well as the combination of all four strategies [Fig. 8(d)]. In each case, the relevant PC scores were added and then restandardized (i.e., transformed into z-scores). These theoretical hybrid profiles may be compared with actual hybrid profiles shown in Fig. 9. Binns [Fig. 9(a)] has a profile with moderate loadings on the first two PCs, a Type I-II profile. It is indeed very similar to the profile in Fig. 8(a) except for bar 1, which seems idiosyncratic. Kentner [Fig. 9(b)] has a Type I-IV profile. It is quite similar to the mixture of PC-I and PC-IV [Fig. 8(b)], though it leans towards Type I in that it shows greater emphasis on within-gesture ritards. (Different mixtures of PC-I and PC-IV result in different relative magnitudes of within- and between-gesture ritards.) Liberace [Fig. 9(c)] exemplifies a Type II-IV profile. It resembles the theoretical mixture [Fig. 8(c)], except in bar 1, which is exaggeratedly Type IV. There is no clear case of a Type I-II-IV profile in the sample, but Volondat's timing [Fig. 9(d)] has nearly equal loadings on all four components and shows the greatly elongated first downbeat characteristic of PC-III as well as an extremely long upbeat. It is very similar to the theoretical mixture of all four PC profiles [Fig. 8(d)] and, not incidentally, to the UPC-I profile (Fig. 4), which is a weighted mixture of all strategies. These examples, at least, look predominantly like combinations rather than alternations of timing strategies.

Whether pianists showing such hybrid timing patterns really entertain several independent cognitive strategies simultaneously remains an open question. Presumably they do not do so consciously, and it may be difficult to prove that they do so subconsciously. What the PC analysis demonstrates is that across different pianists certain timing patterns (the different PCs) are independent of each other while others (the timing of individual gestures within each PC) tend to go together. Thus, for example, the degree of lengthening of the initial downbeat (PC-III) seems to be fairly independent of the timing of later events, and the within-gesture ritards (PC-I) seem to be partially independent of the between-gesture ritards (PC-IV), but within these patterns each type of ritard tends to be applied consistently. However, these are only overall tendencies, and there are numerous individual variations and exceptions.

Two-dimensional scattergrams of the PC loadings for all pairs of PCs are shown in Fig. 10. There is no clear evidence of either clusters or major gaps in these distributions. The space of possible PC combinations seems to be filled fairly evenly by the individual performances. The unidimensional distribution of PC-I loadings is skewed towards high loadings; however, the distributions of the other PC loadings seem fairly symmetrical. The loadings on the different PCs tended to be negatively correlated, for the higher the loading on one PC, the lower the loadings on other PCs must be. The highest negative correlation ($r = -0.42$, $p < 0.001$) was between PC-I and PC-II loadings [Fig. 10(a)], due to the relative rarity of performances with low values on both.

Neither the UPC-I loadings nor any of the PC loadings were correlated with median tempo. PC-III loadings, however, showed a positive correlation with relative modulation depth ($r = 0.30$, $p < 0.01$), and PC-IV loadings a small negative correlation ($r = -0.22$, $p < 0.05$). The lengthening of the initial downbeat in PC-III obviously contributed to a measure of overall timing modulation, whereas the rapid modulations characteristic of PC-IV probably required a relatively low amplitude to be aesthetically acceptable.

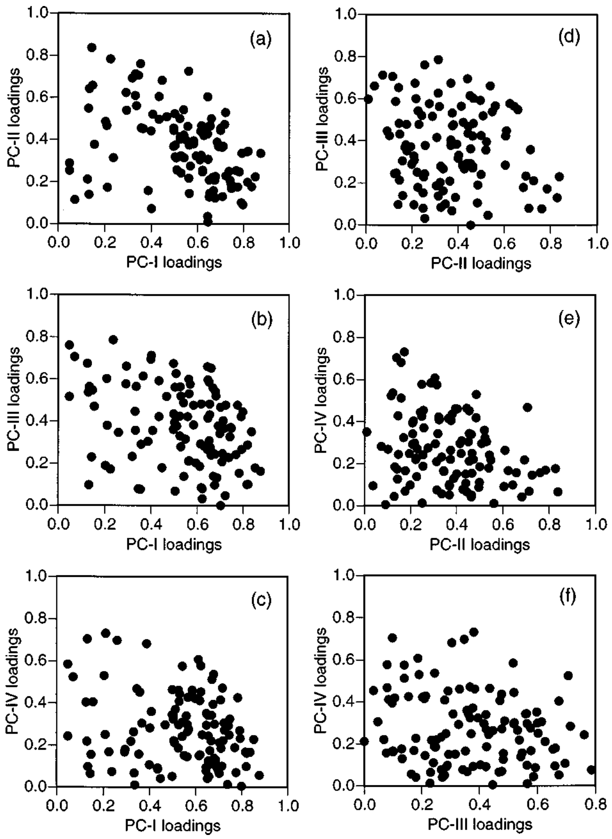

FIG. 10. Scattergrams of positive PC loadings for all pairs of PCs.

G. Similarity among performances

In the course of the PCA the correlations among all possible pairs of timing profiles were computed, a total of (117×116)/2=6786 values, but these were inspected more closely only at a much later stage. Disregarding two outliers (see below), the highest between-performance correlations were 0.929 (Sauer and Mamikonian), 0.921 (Larrocha and Donohoe), 0.920 (Coop and Pokorna), and 0.914 (Weissenberg and Hobson). The first two pairs of profiles are illustrated in Fig. 11. The similarities are indeed striking, although Larrocha and Donohoe have radically different initial upbeat durations and different tempi. Given the large number of correlations computed, it may be concluded that two performances of this excerpt exhibiting a correlation substantially higher than 0.93 are significantly more similar than any two performances by different artists (or, for that matter, by the same artist) are ever likely to be. Even immediately repeated performances by the same pianist may not exhibit such a high correlation, due to uncontrolled timing variation (Repp, 1992, 1995a). When a correlation is higher than 0.99, it is clear that the two performances are identical, with the deviation from a perfect correlation being due to measurement error.[8] This makes it possible to objectively identify copies of a performance (cf. Repp, 1993). The presence of two between-profile correlations of 0.998 in the present sample was a clear indication that there were two pairs of identical performances. One of these turned out to be an accidental substitution of one recording (Aide) for another during preparation of the digital tape at IPA. In the other

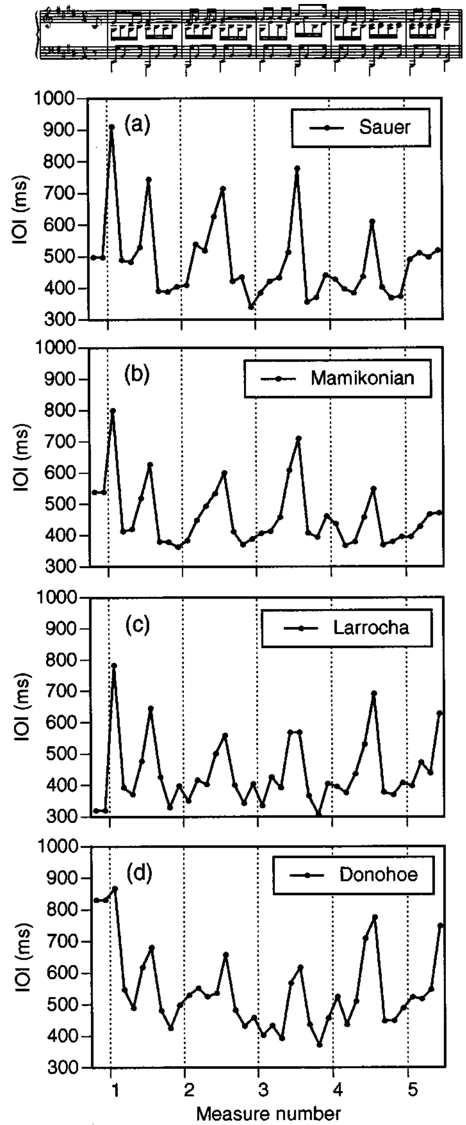

FIG. 11. Two pairs of very similar timing profiles: (a) and (b); (c) and (d).

instance, the performance of a pianist identified on the CD as ''Alexander van der Voss'' turned out to be identical with the performance of Boris Zarankin.[9]

One point of interest was the similarity of different recordings by the same pianist. In an earlier analysis of timing in Schumann's ''Träumerei,'' Repp (1992) found that repeated performances by Cortot and Horowitz, each of whom was represented by three different recordings made years apart, were more similar to each other than to any other pianist's performance in the sample ($n=28$). In the present, much larger sample of much shorter excerpts, seven pianists (Arrau, Ashkenazy, Cortot, Cziffra, Egorov, Horowitz, and Slenczynska) were represented by two recordings each. Egorov's performances were recorded in successive years, Cortot's 9 years apart, and the others 15–30 years apart. The correlation between each pianist's two performances was compared with the 2×115=230 correlations between each of his or her two performances and all other performances. In Egorov's case, none of these 230 correlations was larger than his own correlation (0.851), which is impressive evidence of his consistency but is perhaps not surprising in view of the short interval between his two recordings. In Cortot's case, only seven correlations were higher than his own (0.744). For the other pianists, however, there was not much evidence of consistency in timing. For Arrau, Horowitz, and Slenczynska, the number of correlations exceeding their own (0.713–0.745) ranged from 38 to 66 and thus was still a good deal smaller than the 115 expected by chance. For Ashkenazy (0.648) and Cziffra (0.413), however, there was no statistical evidence at all that their timing came from the same pianist. This indicates that individual timing patterns for the same music can change quite substantially over a number of years. Little is known objectively about the extent to which they can change over shorter time spans, such as months, weeks, or days, though one often hears the informal claim that a particular artist ''never plays the music the same way twice.'' Thus it is not known whether each pianist's recorded timing pattern is representative of his or her approach (at the time of recording, at least) or whether it is merely one of several possible timing patterns that the artist had available simultaneously. This, together with the relatively small sample size, makes it difficult to investigate the relation of timing to sociocultural variables.

H. Sociocultural variables

The investigation of possible influences of artists' year of birth, educational history, age, recording date, nationality, or gender on expressive timing was not a primary purpose of this study, and additional library research would have been necessary to determine biographical information firmly and completely. However, leaving aside educational history (which is difficult to quantify in any case), the artists' gender was certainly known, their nationalities and recording dates were fairly well documented (some were reasonable guesses), and birth dates for a majority of the pianists could be found in books by Methuen-Campbell (1981) and Kehler (1982), with some reasonable guesses added and the remaining dates left blank. Age at the time of recording was, of course, the difference between the recording date and the birth date, if available. Thus it was possible to examine in a preliminary way the relationships between these five sociocultural variables and the objective measurements discussed above: median tempo, relative modulation depth, the initial upbeat ratios (Fig. 3), the typicality index (UPC-I loadings), and the loadings on the rotated PCs.

Recording date was significantly related to three variables. One weak relationship was with the ratio shown in Fig. 3(a) ($r=0.22$, $p<0.05$), indicating a slight tendency for the upbeat to get longer in recent decades. More interestingly, there was a positive correlation with PC-I loadings ($r=0.27$, $p<0.01$) and a negative correlation with PC-II loadings ($r=-0.39$, $p<0.001$). This indicates a trend for Type I timing to increase and for Type II timing to decrease in recent decades. In other words, timing is becoming more typical or mainstream, which is in agreement with many critical writings on modern performance practice. However, the correlation with the UPC-I loadings was not significant. Also, because other sociocultural variables are not equally represented over the decades, it is perhaps safer to conclude merely that, in the present sample, the more recent recordings tended towards the most common timing strategy (PC-I).

Artists' birth dates showed similar correlations with PC-I loadings ($r=0.30$, $p<0.01$) and PC-II loadings ($r=-0.35$, $p<0.01$). Of course, year of birth was highly correlated with year of recording ($r=0.79$, $p<0.001$). In addition, birth date showed a small correlation with PC-IV loadings ($r=0.25$, $p<0.05$), suggesting a tendency for Type IV patterns to be somewhat more common in younger generations.

Pianists' age at the time of recording was negatively correlated with both UPC-I loadings ($r=-0.23$, $p<0.05$) and PC-I loadings ($r=-0.22$, $p<0.05$), which indicates a slight tendency for older artists to exhibit more unusual timing patterns. Pianists' age was unrelated to the year of recording ($r=-0.06$), but it was negatively correlated with their year of birth ($r=-0.66$, $p<0.001$): Pianists born longer ago were generally recorded at a later stage in their career than pianists born more recently. This is largely due to the dual cutoffs imposed by the beginning of acoustic recording (when artists born long ago were already old) and by the present (when artists born recently are still young). In addition, there are now many more opportunities for young artists to be recorded than there were some decades ago.

The effect of gender was assessed by conducting one-way analyses of variance on the various dependent variables. Gender proved to be unrelated to any timing profile characteristics, but there was a significant effect on initial upbeat duration, especially relative to the following downbeat IOI [the ratio shown in Fig. 3(b)]: Men tended to play longer upbeats than women [$F(1,113)=7.6$, $p<0.007$]. In addition, there was a marginally significant tendency for women to play faster than men [$F(1,113)=4.2$, $p<0.05$], and a nearly significant tendency for women to play longer initial downbeats than men [$F(1,113)=3.7$, $p<0.06$], which contributed to the gender difference in relative upbeat duration.

The effect of nationality was difficult to assess because of the many different countries of birth. Therefore the analysis was restricted to those nationalities that were not only well represented in the sample but also have a strong tradition of Chopin performance: French, Polish, and Russian. One-way analyses of variance were conducted accordingly. Only one significant effect emerged, on PC-I loadings [$F(2,39)=4.8$, $p<0.02$]: French pianists were less likely to have Type I timing profiles than their Polish and Russian colleagues.

III. GENERAL DISCUSSION

This study continues a series of investigations of commonalities and differences in distinguished pianists' expressive timing, as measured from commercial acoustic recordings of the same composition (Repp, 1990, 1992, 1997b). The musical excerpt was short, but the sample of recordings was much larger than in previous studies. A mere five bars of music can give rise to a rich diversity of expressive actions, and the large sample made it possible for the first time to map out the ''space'' of aesthetically acceptable timing patterns for a musical passage.

The timing space was defined by six dimensions: basic tempo, relative modulation depth, and the four rotated principal components that describe profile shape. One important finding of this study is that, within this space, there were no distinct clusters of timing patterns. Rather, the space of possibilities seemed to be ''sampled'' by individual performers in a rather continuous way.[10] This suggests that individual differences in timing did not arise from alternative, categorically different structural interpretations of the music. Indeed, the passage does not seem to contain structural ambiguities that need to be resolved by performers. Melodic-rhythmic groups, harmonic progression, and metrical structure are all well defined and mutually supportive. Perhaps the only anomaly is that, due to the final notes of melodic groups and coincident harmonic changes, the second downbeat in each bar (position 5) seems more salient than the first (position 1). However, this does not necessarily reflect a shift in underlying metrical structure, and the data indicate that performers were not faced with a metrical ambiguity requiring a categorical decision. To the extent that interpretation of metrical structure influenced timing at all—and the slow tempo makes that doubtful—it was a matter of deciding on some degree of relative emphasis of first versus second downbeats. Thus, viewed from a metrical perspective, pure Type I profiles focused strongly on second downbeats, whereas pure Type IV profiles gave somewhat more prominence to first downbeats, with many gradations in between.

In view of the relatively homogeneous distribution of individual performances in the timing space, the different profile types (PC patterns) were considered not structural interpretations but timing strategies, i.e., different ways of articulating the same musical structure. In other words, these timing patterns and their combinations primarily convey such things as individuality, motion, and affect within a given structural frame. They give the musical object a particular shape or character (cf. Shaffer, 1996), much as different drawings or paintings of the same object do. The resulting qualities are difficult to describe in words, though some may be captured by imaginative metaphor (which will not be attempted here). The musical structure defines boundaries within which artists' imagination may roam freely.

It is possible to think of structural interpretation in terms of continuously adjustable parameters, and in that case expressive timing may be understood as the parametrization or shaping of a given structure. The grand average timing profile (Fig. 4) may be regarded as a graph indicating the temporal coherence or flexibility of the structure: The higher the value on the ordinate, the more ''stretchable'' the music is at that point, according to the actions taken by a large number of distinguished musicians. Each individual artist, however, creates a personal version of this general temporal shape. While any individual timing pattern could in principle be motivated by explicit or implicit structural considerations—a desire to give more or less emphasis to this or that structural aspect of the music—it is far from clear that this is the motivation behind most artists' expressive strategies. Similarly, there is probably only a small number of music lovers who listen to music in order to be informed about its structure. Although it is always possible to view expression as being *about* the musical structure, this approach misses the essence of musical communication, which is to move listeners and to stimulate their imagination (cf. Cook, 1990; Scruton, 1997). Therefore expression is regarded here as being *constrained* by the musical structure and as communicating living qualities distinct from the structure itself.

The division into two alternating streams, melody and accompaniment, seems to be the most important structural aspect constraining expressive timing in the present Chopin excerpt. When the melody is moving, the accompaniment moves along with it and contributes only to texture and harmony; it comes to the fore only when the melody stands still. Most expressive tempo modulations are nested within the alternating stream segments and employ the conventional strategies of slowing before a boundary and/or accelerating after a boundary. In particular, the pronounced lengthening of the IOI immediately following the onset of a long melody note, which is typical of the Type I timing strategy [Fig. 6(a)] and also can be seen in the Type IV pattern [Fig. 6(d)], helps segregate the melody from the accompaniment. A lengthening of the IOI preceding a melodic gesture is less common but by no means rare and usually occurs together with ritards within melodic gestures. This strategy (Type IV) lends a gestural quality to the accompaniment as well as to the melodic segments and thus elevates the accompaniment from mere background to something like a partner in a dialogue or an echo of the melodic rhythm.

The lengthening of the initial downbeat (Type III) is largely independent of other timing strategies, though it also tends to occur together with within-gesture ritards (Type I). Indeed, it is itself a within-gesture ritard, for the first melodic segment is divided into two smaller gestures, the first of which comprises only the initial upbeat and the following downbeat. The Type III strategy may be considered what Heiles (1964) has called a ''nuance of establishment.'' This designation applies even more, however, to the lengthening of the initial upbeat. Interestingly, that tendency was shown more strongly by male than by female pianists. It may be understood as an attempt to establish control over an audience by capturing its attention through postponement of the anticipated downbeat.

The most interesting timing strategy is the one termed Type II, which (in its ''pure'' form) does entirely without within-gesture ritards and instead shows gesture-initial lengthening followed by acceleration through the following accompaniment in bars 1, 2, and 5, together with a relative lack of temporal modulation in the two linked melodic gestures of bars 3 and 4. It shifts emphasis from the ends of the melodic gestures to their beginnings. Leaving aside subjective judgments for the time being (see Part III of this study), the unusual character of the Type II pattern is suggested by the results of perceptual experiments requiring the detection of small deviations from metronomic timing in the very same Chopin excerpt (Repp, 1998a, 1998b, 1998c, in press). This indirect method revealed that listeners (with or without musical training) have perceptual biases or ''expectations'' of timing modulations that match the ''typical,'' grand average timing profile (Fig. 4). This is the kind of timing that the musical sound structure seems to ''demand'', as it is automatically elicited in listeners' perceptual systems. The Type II pattern is the one most different from the typical profile and from listeners' timing expectations. That it nevertheless can be used with good aesthetic effect is testimony to the inventiveness and skill of the artists who employ it. Clarke (1985, p. 233) has observed that ''a piece with an unambiguous and readily comprehensible structure may encourage a performer to experiment with contradictory expressive elements,'' and the Type II pattern seems to represent such an experimentation.

The four types of timing pattern extracted from the data are descriptive tools, no more. They reduce three-fourths of the variance among 115 different performances to combinations of just four basic patterns. Whether these patterns have any psychological reality as independent cognitive strategies remains uncertain. Most individual timing profiles are mixtures of types, but subjectively they probably appear unified to artists and listeners. Most pianists probably follow their musical instincts, particularly at this level of detail, and simply play with the expression that ''feels right'' for the music. Their musical instincts are shaped in turn by their past experiences as performers and listeners, both with music in general and with the specific passage in particular. Experience increases their explicit and implicit knowledge of the expressive actions that are aesthetically viable within a given musical structure. Inexperienced pianists and amateurs tend to play with conventional expressive timing, the profile that is most compatible with the musical structure (Repp, 1995a, 1997a). Greater experience yields a greater arsenal of options that can be explored.

The smallest unit of expressive action is the gesture, which can be a single note but usually comprises a group of several successive notes. Each expressive gesture in a melody could in principle be shaped differently. However, the regularities within the Type I, II, and IV patterns indicate that similar gestures tend to be shaped similarly. Yet there are many possible individual variants resulting from mixtures of these patterns, and the additional idiosyncratic variance, not accounted for in the PC analysis, should not be forgotten. Also, the Type II pattern is interesting because it does not extend the temporal shaping of bars 1 and 2 to bars 3 and 4. By giving different melodic gestures different expressive characterizations, this timing strategy creates contrast and variety within the phrase.

Todd's (1985) model of expressive timing postulates smooth acceleration–deceleration shapes for whole phrases, so that smaller gestures would be nested in a larger gesture. Although such a large curvilinear trend can be seen in some individual profiles [e.g., Fig. 5(d)], it is not characteristic of most of them. Todd's model tends to be more successful in accounting for the coarse timing patterns in larger hierarchical structures than for the detailed shaping within a phrase (see Windsor and Clarke, 1997; Penel and Drake, 1998).

As already pointed out, the stability of individual artists' timing patterns is essentially unknown. While some pianists may be highly consistent over a number of years, others may be more variable in a deliberate or spontaneous way. The present data provide several examples of artists whose timing profile changed radically over a number of years, but it is unclear how representative the profiles are of the pianist's playing at the time of each recording. Perhaps similarly large changes could be observed within much shorter time spans. This is an interesting topic for further investigation.

While several significant correlations were found between objective parameters of timing and sociocultural variables, they were uniformly small and should be regarded with great caution. The present sample is still quite insufficient for an investigation of that sort, the representativeness of individual artists' profiles is unknown, the sociocultural data are incomplete, and there are numerous confounding variables. At best, the results provide intriguing leads to be followed up in future studies. In seems likely, however, that individual differences far outweigh any sociocultural or historical trends in expression.

Timing is only one aspect of expressive performance, though a very important one. What is being timed or paced are the motor actions that generate the musical sound. The sound heard by a listener is shaped by expressive dynamics (the relative intensities of the notes), articulation, pedaling, instrument acoustics, room acoustics, and sound engineering in recordings. One important question is whether expressive timing is independent of expressive dynamics at the detailed level considered here or whether these two parameters are linked. This issue will be addressed in Part II of this study in the context of a detailed analysis of expressive dynamics in the present sample of performances.

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APPENDIX: RECORDINGS, TEMPI, AND PC LOADINGS

Year=year of recording (~=estimated), MT=median tempo (quarter-note beats per minute), PC-I, PC-II, PC-III, PC-IV=rotated principal component loadings.

Pianist	Label	Year	MT	PC-I	PC-II	PC-III	PC-IV
Aide, William	Musica Viva 1017	1987	25.9	0.650	0.464	0.272	0.042
	(duplicate)			0.656	0.465	0.279	0.052
Anda, Géza	Fonit Cetra CDE 1018	1965	33.3	−0.133	0.485	0.106	0.419
Anievas, Agustin	Seraphim 60081	~1967	26.5	0.331	0.610	0.447	0.264
Arrau, Claudio	Electrola EH 386	~1930	26.0	0.628	0.420	0.284	0.250
	Angel 35413	1956	28.0	0.434	0.606	0.423	0.092
Ashkenazy, Vladimir	Melodiya 10-00511	1959	28.5	0.718	0.473	−0.033	0.222
	London 414 127-2	~1974	30.4	0.691	0.369	0.379	0.094
Backhaus, Wilhelm	Pearl GEMM CD 9902	1927	24.6	0.048	0.255	0.762	0.243
Badura-Skoda, Paul	Westminster XWN-18811	~1960	36.0	0.701	0.445	0.468	0.066
Berezovsky, Boris	Teldec 73129	1991	32.6	0.798	0.092	0.446	0.005
Bingham, John	Meridian 84221	1993	29.5	0.542	0.315	0.139	0.576
Binns, Malcolm	Pearl 9641	1995	27.7	0.645	0.605	0.285	0.091
Biret, Idil	Naxos DDD 8.550364	1990	33.3	0.345	0.707	0.080	0.468
Brailowsky, Alexander	RCA Victor LM-6000	~1947	30.5	0.292	0.624	0.578	0.168
Browning, John	RCA Victrola 60131-2-RV	1968	34.1	0.713	0.369	0.404	0.101
Cherkassky, Shura	HMV ALP 1310	1955	26.5	0.569	0.276	0.577	0.276
Ciani, Dino	Ars Nova VST 6092	1965	27.1	0.156	0.377	0.471	0.406
Ciccolini, Aldo	Capitol SP 8651	1967	25.9	0.504	0.374	0.068	0.222
Cliburn, Van	RCA Victor 60358-2-RG	1961	26.7	0.793	0.336	0.268	0.233
Coop, Jane	Musica Viva 1015	1987	32.3	0.668	−0.001	0.560	0.343
Cortot, Alfred	EMI Classics 2905401	1933	34.9	0.148	0.659	0.548	0.157
	Pathé FJLP 5050	1942	35.7	−0.082	0.828	0.130	0.177
Costa, Sequeira	Supraphon 111 2188	1976	26.5	0.709	0.132	0.248	0.186
Crown, John	Co-Art 5047	~1947	31.8	0.541	0.423	0.488	0.310
Cziffra, György	Philips 6515.005	~1964	35.6	0.357	0.455	0.292	0.452
Cziffra, György	EMI C 167-73103/4	1981	30.0	0.698	−0.319	0.343	0.078
Darré, Jeanne-Marie	Pathé DT 1016	~1953	35.2	0.661	0.500	0.241	0.111
Donohoe, Peter	EMI 54416	1993	29.2	0.745	0.195	0.372	0.249
Drzewiecki, Jaroslav	Canyon 3645	1992	28.7	0.661	0.142	0.654	0.175
Duchâble, François-René	Erato 45178	1981	28.1	0.742	0.209	0.328	0.293
Egorov, Yuri	Peters Int. PLE 121	1978	35.0	0.677	0.124	0.245	0.537
	MHS 4493	1979	34.0	0.675	0.209	0.097	0.395
Ellegaard, France	Siemens 17919	~1939	27.8	0.614	0.440	0.294	0.151
Entremont, Philippe	Sony Classical MLK 64057	~1973	29.3	0.503	0.319	0.563	0.344
Farrell, Richard	EMI 64136	1958	26.5	0.644	0.428	0.268	0.078
Fou Ts'ong	CBS 61886	1980	41.2	0.209	0.467	0.603	0.251
François, Samson	EMI C 163-5323/7	1959	33.5	0.132	0.140	0.098	0.705
Goldenweiser, Alexander	Melodiya M10-42855/6	~1950	27.8	0.595	0.323	0.203	0.423
Goldsand, Robert	Concert Hall H-1632	~1953	23.4	0.819	0.199	0.289	0.099
Goodman, Isador	Austral. Philips 6508 004	1979	30.1	0.225	0.785	0.173	0.169
Haas, Monique	Erato STU 70941	1977	35.8	0.399	0.441	0.696	0.107
Haas, Werner	Philips 836.816	~1965	35.0	0.652	0.210	0.309	0.343
Haase, Erika	Thorofon CTH 2195	1992	40.4	0.681	−0.099	0.521	0.301
Harasiewicz, Adam	Philips Classics 422-282-2	1961	29.0	0.502	0.524	0.395	0.324
Hesse-Bukowska, Barbara	Muza SXL 0611	~1970	29.4	0.652	0.129	0.587	0.044
Hobson, Ian	EMI CFP 4392	1982	31.9	0.791	0.102	0.424	0.270
Horowitz, Vladimir	RCA Victor 60376-2-RG	1951	31.0	0.617	0.326	0.085	0.412
	Sony 53468	1972	38.6	0.686	0.389	0.132	0.131
Iturbi, José	Seraphim S-60186	~1959	30.8	0.447	0.683	0.180	0.042
Janis, Byron	RCA Victor 12-0431	1948	25.8	0.524	0.501	0.425	0.187
Johannesen, Grant	Golden Crest CRS 4101	~1971	30.9	0.529	0.243	0.520	0.444
Joyce, Eileen	EMI OXLP 190 254	1941	30.7	0.319	0.694	0.234	0.219
Kahn, Claude	Epidaure 1946	~1975	31.3	0.508	0.314	0.627	0.211
Karolyi, Julian von	Arkadia 909	1953	31.9	0.654	0.144	0.483	0.127
Katz, Mindru	Pye GGC 4063	1966	22.4	0.611	0.306	0.187	0.608
Kentner, Louis	Capitol GBR 7162	1957	30.4	0.622	0.249	0.080	0.578
Kersenbaum, Sylvia	EMI CFP 40239	1975	30.9	0.467	0.509	0.519	0.297
Kilényi, Edward	APR 7037	1937	29.9	0.558	0.464	0.423	0.340
Koczalski, Raoul	Polydor 67262	1938	31.6	0.134	0.643	0.565	0.099
Koyama, Michie	Sony SRCR 8528	1991	30.1	0.644	0.037	0.661	0.095
Kyriakou, Rena	Vox GBY 12710	1964	22.8	0.237	0.315	0.787	0.075
Larrocha, Alicia de	MHS 1761	~1969	37.1	0.836	0.178	0.352	0.167

Pianist	Label	Year	MT	PC-I	PC-II	PC-III	PC-IV
Levant, Oscar	Columbia ML 4147	~1947	28.9	0.622	0.256	0.032	0.454
Liberace	Columbia ML 4900	~1955	25.3	0.204	0.486	0.191	0.530
Licad, Cecile	MusicMasters MM 67124	~1994	28.7	0.852	0.226	0.180	0.228
Lopes, Fernando	Unicamp LPFL 021/2	1986	26.9	0.748	0.170	0.368	0.325
Lortat, Robert	Dante 025	~1931	26.9	0.144	0.838	0.231	0.065
Lortie, Louis	Chandos CHAN 8482	1986	26.7	0.211	0.174	0.381	0.732
Magaloff, Nikita	Philips 6542 411	1975	29.0	0.354	0.762	0.077	0.158
Magin, Milosz	Festival classique 701	1969	25.9	0.584	0.395	0.384	0.462
Malcuzinsky, Witold	British Columbia LX 1203	~1948	28.8	0.564	0.375	0.532	0.265
Mamikonian, Vardan	Calliope 9220	1993	36.0	0.775	0.177	0.478	0.070
Manz, Wolfgang	Astoria 87008	~1985	33.7	0.646	0.308	0.416	0.296
Murdoch, William	Decca K 704	~1938	32.0	0.294	0.540	0.662	0.180
Niedzielski, Stanislaw	Westminster WL 5340	1955	21.8	0.702	0.455	0.000	0.213
Novaes, Guiomar	Vox PL 10930	~1950	33.7	0.336	0.562	0.566	0.011
Paderewski, Ignace Jan	Pearl 9397	1927	35.8	0.540	0.543	−0.040	0.242
Pennario, Leonard	Capitol P 8391	1957	27.2	0.618	0.467	0.483	0.155
Penneys, Rebecca	Centaur 2210	1993	31.6	0.670	0.160	0.140	0.513
Perahia, Murray	Sony SK 64399	1994	33.4	0.366	0.452	0.615	0.305
Perlemuter, Vlado	Nimbus NI 5095	1983	32.2	0.048	0.289	0.517	0.585
Pokorna, Mirka	Supraphon GMM 90	~1967	23.1	0.646	0.010	0.598	0.352
Pollini, Maurizio	DGG 413 794-2	~1971	34.4	0.562	0.727	0.212	0.146
Ranki, Dezsö	Hungaroton 11555	~1975	32.4	0.876	0.336	0.164	0.057
Renard, Rosita	VAIA/IPA 1028	1949	37.7	0.769	0.255	0.244	0.189
Richter, Sviatoslav	Philips 420 774-2	1958	30.4	0.722	0.530	0.047	0.306
Saperton, David	VAIA/IPA 1037-2	1952	27.1	0.549	0.401	0.317	0.152
Sasaki, Ken	Nimbus 2136	1982	32.3	0.565	0.146	0.214	0.428
Sauer, Emil	Parlophone E 10863	1928	34.5	0.679	0.227	0.543	0.139
Schein, Ann	Japanese CBS WS-10001	~1966	29.5	0.782	0.249	0.154	0.426
Shebonova, Tatiana	Melodiya A10 00217	1985	27.6	0.497	0.455	0.362	0.345
Simon, Abbey	Vox TV-34688	1977	33.5	0.511	0.258	0.378	0.371
Skavronsky, Alexei	Melodiya 10-00249	1986	25.0	0.528	0.325	0.280	0.409
Slenczynska, Ruth	Decca DL 9890	1956	27.3	0.333	0.714	0.358	0.068
	MHS 3216	~1975	30.8	0.434	0.497	0.593	0.087
Slobodyanik, Alexander	Melodiya/Angel SR40204	1977	24.9	0.525	0.403	0.332	0.461
Smith, Ronald	Nimbus 5224	1990	29.3	0.401	0.073	0.714	0.283
Sofronitzky, Vladimir	Melodiya M10 42253/64	1960	34.2	0.130	0.549	0.538	0.219
Solomon	EMI RLS 701	1945	25.9	0.526	0.415	0.565	0.297
Székely, István	Naxos 8.550083	1987	28.6	0.387	0.159	0.305	0.682
Timofeyeva, Lyubov	Melodiya 10-00071	1985	34.5	0.407	0.521	0.357	0.360
Uninsky, Alexander	Epic LC 3065	~1954	33.6	0.563	0.218	0.601	0.299
Varsi, Dinorah	Intercord 160.842	1981	47.4	0.071	0.116	0.707	0.524
Vásáry, Tamás	DGG 2535 266	1965	30.5	0.260	−0.015	0.348	0.698
Vered, Ilana	Connoisseur CS 2045	1972	27.3	0.654	0.147	0.432	0.245
Virsaladze, Elisso	Melodiya C10-05443/6	~1980	26.4	0.716	−0.005	0.368	0.472
Volondat, Pierre-Alain	EMI 173199	1984	23.7	0.498	0.444	0.436	0.464
Weissenberg, Alexis	EMI 69114	1979	28.5	0.724	0.230	0.478	0.272
Wild, Earl	Chesky CD 77	1992	27.2	0.666	0.223	0.252	0.221
Woodward, Roger	Austral. EMI OASD 7560	~1975	32.1	0.707	0.365	0.209	0.416
Woytowicz, Boleslaw	MHS OR C-150/1	~1960	29.6	0.497	0.369	0.675	0.052
Yamazaki, Takashi	Fontec FONC 5027	1980	29.4	0.126	0.213	0.675	0.404
Yokoyama, Yukio	Sony SK 62605	1995	28.5	0.584	0.381	0.477	0.437
Zarankin, Boris	Mastersound 018	1990	23.4	0.816	0.344	0.100	0.168
(duplicate, ''v. d. Voss'')	Orchid 11033	1990	23.3	0.821	0.346	0.101	0.163
Zayas, Juana	Spectrum 165	1983	35.7	0.737	0.251	0.229	0.013

[1]The old edition from which the music has been copied is no longer considered authoritative, and the tempo indication is plainly wrong. However, in the initial bars it does not differ significantly from modern Urtext editions, except in graphic layout and added fingering suggestions. It has the unique advantage of fitting the first five bars into a single system, and it also served as the model for the simplified, computer-generated score used in later figures.

[2]Most analyses include all 117 samples, as they were conducted before the duplication was discovered. It seemed unnecessary to redo the analyses in view of the minimal difference this would have made in the results.

[3]The classification is according to country of birth (which, in some cases, is merely a best guess). No heed was paid to the fact that some of the pianists were trained and/or lived in other countries most of their life (e.g., Arrau, Cherkassky, Fou Ts'ong, Magaloff, Weissenberg), so that they cannot really be considered representative of any pianistic school or performance tradition associated with their country of birth.

[4]A number of performances (at least 29) contained one or more such asynchronies. In nearly all instances, one or several lower tones (played by the left hand) preceded a melody tone, and the majority (59%) occurred on metrical downbeats. Pianists particularly inclined to employ such left-hand-leads (five or more times) were Paderewski (who arpeggiated most chords), Slenczynska (in both of her recordings), Saperton, Ciccolini, Janis, and Liberace. As is well known, this expressive strategy or mannerism tends to be more common in artists of older generations.

[5]A third possibility is to base the tempo estimate on the modal IOI (the peak of the IOI distribution), but this is not very accurate with only 36 IOIs.

[6]In view of the great length of the inter-beat intervals, it may be argued that the primary beat (tactus) is really at the eighth-note level, in which case the tempi should be multiplied by two.

[7]Ideally, to make the profiles more comparable in terms of relative modulation depth, a logarithmic scale should have been used on the *y* axis of the graphs. However, a linear scale proved more convenient in view of certain limitations of the graphics software.

[8]Of course, the two performances would not be identical if they differed in tempo and/or modulation depth and/or initial upbeat duration, but such differences are extremely unlikely in the presence of such a high timing profile correlation and would suggest deliberate manipulation of a sound recording.

[9]The author has not seen these CDs but, according to Donald Manildi of IPA, Zarankin's identity is not in doubt.

[10]Admittedly, this conclusion was drawn on the basis of two-dimensional plots only, but it seems unlikely that a consideration of higher-dimensional spaces would have led to a very different conclusion. Of course, the full six-dimensional timing space is only sparsely ''populated'' and leaves almost infinitely many possibilities for individual timing patterns, without exceeding the constraints defined by the present sample of performances.

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