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Mapping Musical Thought to Musical Performance

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Expressive timing methods are described that map pianists' musical thoughts to sounded performance. In Experiment 1, 6 pianists performed the same musical excerpt on a computer-monitored keyboard. Each performance contained 3 expressive timing patterns: chord asynchronies, rubato patterns, and overlaps (staccato and legato). Each pattern was strongest in experienced pianists' performances and decreased when pianists attempted to play unmusically. In Experiment 2 pianists performed another musical excerpt and notated their musical intentions on an unedited score. The notated interpretations correlated with the presence of the 3 methods: The notated melody preceded other events in chords (chord asynchrony); events notated as phrase boundaries showed greatest tempo changes (rubato); and the notated melody showed most consistent amount of overlap between adjacent events (staccato and legato). These results suggest that the mapping of musical thought to musical action is rule-governed, and the same rules produce different interpretations.

Music performance is characterized by many temporal deviations from the written material, which are assumed to be related to the performer's intended meaning or to structural aspects of the material being produced. Most approaches to the correspondence between intended meaning and musical performance are based on examination of the microstructure of a performance: the minute variations in timing, pitch, intensity, and timbre that characterize a human performance (Bengtsson & Gabrielsson, 1983; Rasch, 1979; C. E. Seashore, 1938; Shaffer, Clarke, & Todd, 1985). Some cases of performance variations are relatively uninteresting; they include random fluctuations due to noise in the system (such as limits in muscular control or lapses of attention). In other cases, the variations are intentional and are related to structural features of the material chosen for emphasis by the performer. Two methods for studying the relationship between expressive timing variations in music performance and musical intentions are described here: the comparison of live performances with the performers' notated musical intentions and the comparison of (intended) musical and unmusical performances.

The relationship between structural content and timing variations in performance depends in part on the musician's intentions, or choice of structural content for emphasis. Often what differentiates one performance from another is the performer's interpretation of the music. By *interpretation* I mean the performers' individualistic modeling of a piece according to their own ideas or musical intentions (Apel, 1972). Some of these intentions may be unconscious or automated; in motor theory terms, certain intentions to perform skillfully may be information input to a motor program that forms the basis for constructing specific, primarily unconscious motor representations leading to performance (Shaffer, 1981). Other intentions, the types discussed in this article, include conscious choices of appropriate musical structure for emphasis, such as melody, phrasing, and dynamics. Nakamura (1987) demonstrated a correspondence between pianists' conscious interpretation of dynamics (variations in loudness) and the measurement of intensity changes in the performances. Furthermore, the dynamics of the performances were understood by listeners who notated what they believed were the performers' intentions. Although no temporal aspects of interpretation were studied, the research suggests that the relationship between performers' intentions and performance timing may also aid listeners' musical understanding.

The mapping between structural content and performance timing has been studied in many contexts, including speech (W. E. Cooper & Paccia-Cooper, 1980; Grosjean, Grosjean, & Lane, 1979), music (Nakamura, 1987; Sloboda, 1983), and other motor tasks (Shaffer, 1976). Related theoretical positions studying this mapping include branches of linguistics, music theory, and motor programming. Both linguistic and music theories attempt to express formal relationships between syntactic (structural) and phonetic (sounded) representations. Linguistic theories differ from music theories in many aspects, most noticeably the lack of an equivalent for semantics in music. However, there are two common components to the theoretical approaches: Linguistic theories seek to describe the mental properties of a native speaker of a language in a formal grammar that models the hearer/speaker's knowledge. Most grammars are characterized by a finite set of rules that through novel combination can generate a wide variety of instances in a language. Grammars have also been devised for musical styles, such as Swedish nursery tunes (Sundberg & Lindblom, 1976) and jazz chord sequences (Steedman,

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1984), and for the structural interpretation of music listeners (Lerdahl & Jackendoff, 1983).

The second common component modeled in both linguistic and music theories is rhythmic organization or accent placement. Rhythmic or metrical stress in language is usually considered to be a phonological component, mediated only indirectly by intended meaning (e.g., Selkirk, 1984). The rhythmic stress assignment in linguistic descriptions of structure-to-sound mappings incorporates some of the same principles of cognitive organization found in descriptions of musical rhythm, including hierarchical properties of nestedness, recursion, periodicity, and some degree of independence from intonation or tonal organization.

Studies of motor control in skills such as speech, music, and typing also model performance timing. A skilled motor performance is governed by a grammatical, limited set of procedures for translating intentions into actions, an abstract generative process that allows greater flexibiltiy, fluency, and expressiveness than in unskilled performance (Rosenbaum, 1985; Shaffer, 1981). *Motor programming* refers to the memory representation for the organization (prior to execution) of a sequence of commands to the performing muscles (Keele & Summers, 1976; Rosenbaum & Saltzman, 1984). Motor programs may contain the intended action, along with procedures that translate these intentions into specific movement sequences. Again, there are two components to these motor control approaches that may apply to a theory of music performance: The first is the prediction that performance timing is not directly specified but instead emerges as a function of a motor program's implementation in multiple procedures. This view corresponds well with skilled music performance, in which a complex timing output is often considered the indirect consequence of several simultaneous goals, including musical expressiveness, finger and hand movements, and often breathing. The question raised is: what are the procedures governing the translation of musical intentions to performance timing?

The second application from motor theory is the growing suggestion that motor programs governing voluntary movement sequences have parameters whose values can change (Rosenbaum, 1985; Schmidt, 1976; Van Galen & Wing, 1984). The use of parameters is considered economical, because it allows flexible adjustments to preexisting motor programs to produce different performances, thus reducing storage load and search time. One application of parameter theory to music is to question whether musical performances differ from one another in terms of the parameter values assigned to preexisting motor programs. Alternatively, different programs may be combined (with or without parameters) during different musical performances. If the parameter hypothesis applies to music performance, then different performances by the same performer may contain the same programs applied with different parameters.

Two related questions from the linguistic and motor control approaches are addressed to music performance in this article: First, can a musical performance be explained by a set of procedures that map intentional expression of structural content to the complex timing output? And second, do the procedures differ or do their parameters differ from one performance to another? If a limited set of procedures with varying parameters do characterize the timing of a musical performance, then they may serve to generate the set of possible performances for a given musical intention.

Several studies of piano performance have demonstrated timing deviations from a literal or mechanical execution of the musical notation that are related to aspects of musical structure (Clarke, 1985; H. G. Seashore, 1937; Shaffer et al., 1985; Todd, 1985). Clarke assessed the effect of metrical context on piano performance deviations, finding that notes in strong metrical positions tended to be lengthened and notes in weak metrical positions tended to be shortened. Sloboda (1983) found that pianists tended to emphasize metrical accents by playing those beats louder and longer. Gabrielsson (1974, 1987) demonstrated in monophonic (single-voiced) and polyphonic music that performance of musical rhythm is characterized by systematic variations in note durations in relation to the strict mechanical regularity of the notated score. Rhythms based on integer ratios were generally larger or sharpened, so that the longer duration was even longer and the short duration shorter (Gabrielsson, 1974, 1987). These deviations from mechanical regularity serve to communicate aspects of musical structure, including meter and rhythm.

Other timing patterns have been described in music performance that are not explicitly notated in the musical score. These include chord asynchronies, rubato patterns, and legato and staccato patterns. The first of these, *chord asynchronies*, refers to the asynchrony between musical events that are notated as synchronous. Western tonal music has been largely polyphonic over the last 600 years, consisting of two or more simultaneous parts or voices. To make performance possible, the temporal relations between the voices must be defined and are usually explicit in the musical notation. Rasch (1979) studied the coordination of parts between chamber ensemble players. Asynchronies between events notated as simultaneous were found for wind and string trio players, with a small lead (less than 10 ms) of the instrument playing the melody, and a 40-ms overall asynchrony across the instruments. A leading melody may be due to different reasons: A chamber ensemble player may serve as conductor for the group's synchronization, or the melody may precede other voices in order to make it perceptually salient. Experienced musicians can perceive temporal asynchronizations as small as 10 ms between the onsets of two notes on a piano (Vernon, 1937), and accurate judgments of perceived ordering can be made for two successive events in a nonmusical context spaced 10–20 ms apart (Hirsh, 1959). An examination of chord asynchronies in piano performance may elucidate the role of a leading voice as a perceptual or coordinating device.

The second timing pattern, found both in music and speech, is the placement of pauses at phrase boundaries. Musical phrases are typically described as units of meaning (Riemann, 1896), often defined by the events at their boundaries (Cogan & Escot, 1976). Pausing and increasing the durations of events at phrase boundaries in speech are assumed to be accounted for by syntactic and prosodic structure (W. E. Cooper & Paccia-Cooper, 1980; Grosjean et al., 1979). Todd (1985) proposed a model for music performance, consistent with this assumption, that predicted *rubato* or tempo changes at structural endings (such as cadences and phrases) by an amount proportional to the hierarchical level or depth of phrase embedding. His model accurately predicted rubato patterns at the phrase level in three piano performances. The rubato patterns were predicted according to a single pianist's performance for each of the musical excerpts chosen; it is unknown how rubato patterns may be manipulated by different performers whose interpretations of syntactic structure differ.

The third timing pattern found in music performance but not in the musical score is the application of legato and staccato, or overlapping note onsets and offsets. *Legato* and *staccato* refer to the amount of overlap in the amplitude envelopes of adjacent notes. *Legato* is a smooth, continuous flow of notes, caused by the offset of one note following the onset of the next note, and *staccato* is an abrupt, discrete patterning of notes, caused by a gap or nonoverlapping offsets and onsets. Sloboda (1983) demonstrated that legato and staccato, as well as loudness and rubato, varied in pianists' performances of a single melodic line as the meter was altered in the musical notation. When the musical notation presented to pianists was changed, the pianists altered their use of legato and staccato patterns to match the meter, so that notes carrying major stess were played more legato than the preceding notes. Legato and staccato patterns, or overlaps, are thought to create perceptual continuity or discontinuity in a melody, but the relationship between the overlaps and the melodic line has not been demonstrated in polyphonic music.

The first goal of the research reported here was to measure three timing patterns in a variety of skilled piano performances and to determine if the patterns served as common procedures that mapped fluent motor programs into specific piano performances. Experiment 1 contrasted the use of the timing patterns in six piano performances of a musical excerpt from the Western piano literature. Relevant questions included: how consistently were patterns used by a performer, what degree of control did a performer have over them, and finally, were there individual differences among performers of varying levels of experience? To address these questions, student and professional musicians were compared, and both musical and unmusical performances were collected.

The second goal of this research was to investigate how a performer's structural interpretation was expressed through these timing patterns in piano performance. If the objective of the timing patterns is to make the underlying musical structure perceptually salient, then their use ought to correspond to the performer's particular interpretation of musical structure. Experiment 2 demonstrated the correspondence between the patterns and the performers' interpretations. Pianists performed a musical excerpt and then notated their interpretations on an unedited musical score. Each of the three timing patterns was analyzed relative to aspects of the notated interpretations. Again, student and expert musicians were compared, and both musical and unmusical performances were collected.

Experiment 1: Performance Timing Methods

The first experiment addressed the use of chord asynchronies, rubato patterns, and legato and staccato patterns in a collection of piano performances. Two types of performances by each pianist were compared: a musical performance and an unmusical performance. An unmusical performance was defined for performers as one in which the performers ought to remove all aspects they considered to be musical, that is, not the opposite of but the lack of musical style. An unmusical performance was defined this way in order to create different performance goals or intentions and thus to test whether the same or different motor programs serve to translate different intentions to actions. If the parameter hypothesis explains how different performances are created by a single performer, then the unmusical performance ought to contain the same procedures applied with different parameters. The comparison of musical and unmusical performances within each pianist also allowed a measure of voluntary control for the timing methods and indicated whether the timing methods were considered part of musical style by the performer.

The role of experience was addressed by comparing pianists of different skill levels. Performances of a musical excerpt from the Western tonal literature were collected from three professional pianists and three students, all of whom were familiar with the music. The pianists performed the opening theme of a piano sonata by Mozart. The excerpt was chosen for several reasons: many pianists are familiar with it; it allows several possible interpretations; and it is representative of the Classical period of musical composition.

Method

Subjects. Six pianists from the Ithaca, New York community were invited to perform the first eight measures of the piano Sonata in A Major, K. 331 by Mozart. Three of the pianists were professional musicians who teach piano and concertize. The other three pianists were student musicians, currently enrolled in private instruction. The professionals had 15 to 37 years of experience performing in public and 15 to 29 years of experience teaching private lessons. The students had 13 to 16 years of private instruction on piano. The division of pianists into students and professionals was based on concertizing and teaching experience and on whether they were currently under private tutelage. The student–professional dimension is a continuum, and there are individual differences, but the more experienced pianists are referred to as experts in this article. Each of the pianists had previously performed the excerpt, and 4 of the pianists (2 students and 2 experts) were familiar with other keyboard instruments, including synthesizers.

Apparatus. The pianists performed on a weighted 88-key velocity-sensitive Yamaha KX88 keyboard, which was monitored by an IBM personal computer. Sound generated by Yamaha TX816 tone generators, operating on FM principles of sound synthesis, was then produced on an Ampex amplifier/speaker set directly in front of the keyboard. The velocity-sensitive keyboard allowed the pianists to control the loudness with which each key sounded by how fast they pressed the key, which was translated into speed of key movement. Each note event was coded a velocity value in the range of 0 (*no sound*) to 127 (*loudest*). Typically, the values during performance fell in the range of 30 to 90. The damper pedal allowed pianists to prolong a note's sound beyond the key release by allowing the sound to continue until the damper pedal was released. The piano timbre was chosen beforehand by a different group of pianists, and the same timbre was used for all performers. The attack of the amplitude envelope was 10 ms to peak amplitude, decaying linearly over the duration of the note, and the release time (time from releasing a key to 0 amplitude) was 80 ms.

The note events were recorded by the computer, and events were assigned clock times to the nearest 2 ms. The precision of the timing system (as measured by the standard deviation) was 0.5% for durations in the range of the performances.

Procedure. Pianists played the excerpt at least two times, which provided a measure of consistency within each pianist. Recordings were made until the pianists heard a performance of their own that they thought was satisfactory. Then they were asked to play an unmusical performance, which was defined as one in which the pianists would remove all aspects of the performance they considered to be musical and would perform not with the opposite of musical style but with a lack of musical style. They were instructed not to add any expressiveness beyond what was notated in the musical score in the unmusical performances; therefore, the pianists attempted to perform strictly according to the musical notation, that is, with the mechanical consistency of the musical score.

Results

Chord asynchronies. The first performance method, *chord asynchrony*, is defined as the difference betweed note onsets that are notated in the musical score as synchronous. For each three-note chord, the difference in onset times between each pair of voices was calculated; the highest voice was coded as melody, the middle voice as Voice 2, and the lowest voice as Voice 3. The standard deviations of the three pairs of voices are used to calculate the root mean square (the square root of the sum of the squared differences between voices). The root mean square is a measure in milliseconds of the overall asynchrony between voices. This measure of asynchrony, defined by Rasch (1979), is shown in Figure 1; the performers are ordered from left to right in all graphs in increasing expertise. The asynchrony across pianists for the musical performances, shown in black, averaged 18 ms. The asynchronies for unmusical performances, shown in shaded bars, averaged 11 ms, and were significantly less than the musical asynchronies, $t(5) = 7.33, p < .01$. Performers seemed to have control over the synchronization between voices, and they utilized it in musical performances.

There were individual differences. The third student, S3, is an advanced student who specializes in the Classical music period, particularly Mozart. His asynchronies most closely resembled the experts. The third expert, X3, who least resembles the other experts, specializes in 20th century music, a style characterized by structural forms quite different from Mozart's period. Only when these two performers were excluded did students and experts show different asynchronies, in that the experts tended to display more asynchrony (mean asynchrony = 21.1 ms) than the students (16.7 ms) when playing musically. When these individual differences were included, experts and students did not differ in amount of asychrony.

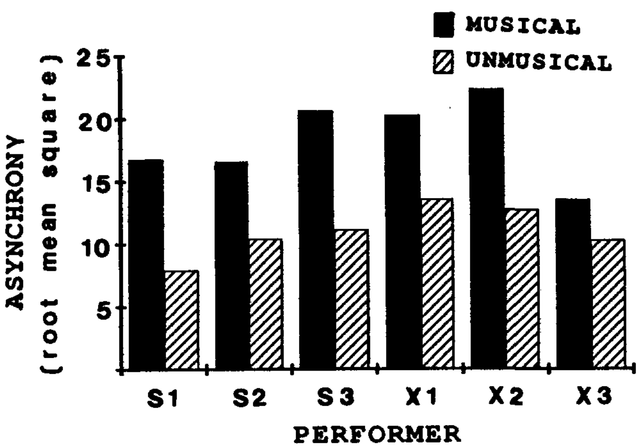

Figure 1. Experiment 1: Chord asynchronies measured in root mean square for musical (black) and unmusical (shaded) performances.

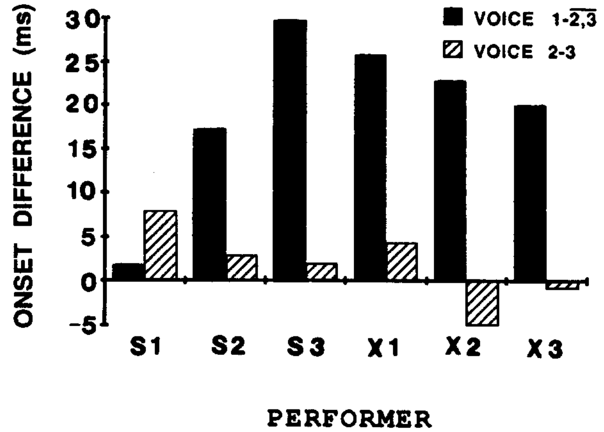

Figure 2. Experiment 1: Chord asynchronies measured in mean onset differences between voices in musical performances. (Difference between melody and remaining voices shown in black bars; difference between Voice 2, alto, and Voice 3, bass, shown in shaded bars.)

To investigate whether or not the chord asynchronies seen in the musical performances reflected leading with the tones in the melody, the difference in onset times between the melody and other voices was calculated. Figure 2 demonstrates the difference in onset times between the melody and the average onset time of the other voices for all three-note chords in the musical performances. The melody significantly preceded the other voices in the musical performances, both on an average, $t(6) = 4.2, p < .01$, and on an individual basis for each performer. The average lead of the melody was 20 ms in the musical performances and 10 ms in the unmusical performances, a significant difference, $t(5) = 2.73, p < .05$. It seems that performers were capable of controlling the amount by which the melody led.

Again there were some individual differences. The student, S3, specializing in this musical period showed a melody lead similar to the experts, and the expert specializing in 20th century music was different from the other experts. Excluding these two performers, the expert performances showed a greater melody lead of 10 ms than the students. This leading melody pattern was consistent on an individual basis, as measured by correlations within pianists on a note-by-note basis from one successive musical performance to another, shown in Table 1.

It is possible that the melodic notes precede the remaining notes in each chord because of a strategy to play them louder by hitting the keys faster and therefore sooner. Consistent

Table 1
Intrasubject Correlations Between Successive Performances for Three Performance Methods

Performer	Asynchrony	Rubato	Overlap
S1	.60*	.96*	.70*
S2	.54*	.89*	.93*
S3	.61*	.93*	.93*
X1	.59*	.96*	.94*
X2	.60*	.97*	.97*
X3	.21	.95*	.96*

Note. Intrasubject correlations calculated on a note-by-note basis. Asynchrony $df = 25$. Rubato $df = 35$. Overlap $df = 27$. S = student; X = expert.
* $p < .05$.

with this, pianists reported an attempt to play the melody louder; no one reported an intention to play it sooner. To distinguish this strategy from that of leading with the melody in time, the temporal onset differences between melodic notes and remaining chord notes were correlated with the velocity differences (which correspond to loudness) for each performer. If a loudness strategy caused the temporal asynchronies, then the differences in velocity ought to be proportional to the temporal onset differences. Four of the 6 performers showed no significant correlation between velocity and temporal onset differences; this argues against the dependence of chord asynchronies on a loudness strategy. Two of the performers showed a significant correlation, a student musician, S2 ($r = .49$, $p < .05$), and the expert specializing in 20th century music, X3 ($r = .48$, $p < .05$).

Rubato patterns. The second performance method, *rubato*, is characterized by shortening and lengthening of individual notes, or deviations from the mechanical regularity of the musical score. The rubato patterns of the students are shown in Figure 3 and of the experts in Figure 4. The deviations from mechanical regularity are plotted by the percentage of deviation from each performer's mean tempo or rate, to allow comparisons across performers. The percentage of deviation for the musical performances, shown by solid lines, is largest around the cadences or phrase endings, points of important musical structure. Another consistent pattern is the shortening of short durations and the lengthening of long durations. All of the lowest percentages correspond to 16th notes, the shortest durations in the score. This finding is consistent with the piano performances of this excerpt reported by Gabrielsson (1987).

The rubato patterns of the unmusical performances are indicated in both figures by dashed lines. The range of rubato for each of the performers decreased in the unmusical performances, which left relatively flat and mechanical renditions. The standard deviations of the rubato patterns, a measure of overall spread, were compared for the musical and unmusical performances. The rubato was significantly greater in musical performances than in unmusical performances for 5 of the 6 pianists (the exception was the expert specializing in 20th century music), as well as across the six performances, $t(5) = 3.94$, $p < .05$.

Finally, there were some individual differences in the rubato patterns. The student, S3, who specializes in music of this period showed a larger decrease in standard deviation of rubato between musical and unmusical renditions than the other two students, and the expert who specializes in 20th century music showed a smaller decrease than the other experts. Although there was no statistically significant difference in standard deviations of rubato between students and experts, when the data for the two individual differences were excluded, the experts exhibited a greater use of rubato than the students in musical performances. The consistency of the rubato patterns within a performer across subsequent musical performances was high, as shown in Table 1.

Overlaps. The third performance rule can be described as the degree of overlap between adjacent notes. *Overlap* was defined in terms of the overlapping time of two adjacent notes' amplitude envelopes. An overlap was calculated as the offset of note event N minus the onset of note event $N + 1$. The offset was defined as the time at which a key is released and the onset was the time at which a key is pressed. In a legato or smooth performance, adjacent notes frequently overlap in time, so that the overlap is a positive value. In a staccato performance there is a gap or silence between the offset of one note and the onset of another note, which results in a negative value. The damper pedal may be used in addition to or in place of fingered overlaps; the damper pedal postpones the normal termination of the piano strings' vibration when a key is released (an offset). Release of the damper pedal terminates the string vibrations. Because none of the pianists used the damper pedal in performances of this excerpt, the overlaps are defined in terms of fingered onsets and offsets.

The mean overlaps for the melody in musical and unmusical performances are shown in Figure 5. Because overlaps were always large and negative at the same phrase boundary in each performance (causing a gap between Measures 4 and 5), the overlaps for the last event in Measure 4 were excluded from the averaged data. Also excluded were the six occurrences on which the same pitch was repeated in the melody (causing the performer to lift the finger, creating a staccato overlap by necessity). In the musical performances, 3 pianists performed legato on average, and 3 performed staccato. (Positive values are legato and negative values are staccato). The unmusical performances were significantly more staccato than the musical performances for 5 of the 6 pianists, and the difference between musical and unmusical renditions was significant for the combined performances as well, $t(5) = 2.63$, $p < .05$. An increased use of staccato is consistent with the sound of the unmusical performances, which is more disjoint. Thus, the amount of overlap appears to be under the control of the performer. Performers were consistent in use of overlaps from one musical performance to another, as shown in Table 1. Individual differences were reflected in the style, that is, the choice of a legato or staccato performance, rather than a student–expert differentiation.

To express the amount of overlap relative to the surrounding note durations and independent of the individual performer's tempo, a regression model was designed to predict the amount of overlap from the surrounding note durations on which the overlap was calculated. Thus, each overlap in the melody was coded in terms of the adjacent note durations as given in the musical score (a sixteenth-note was coded as 1,

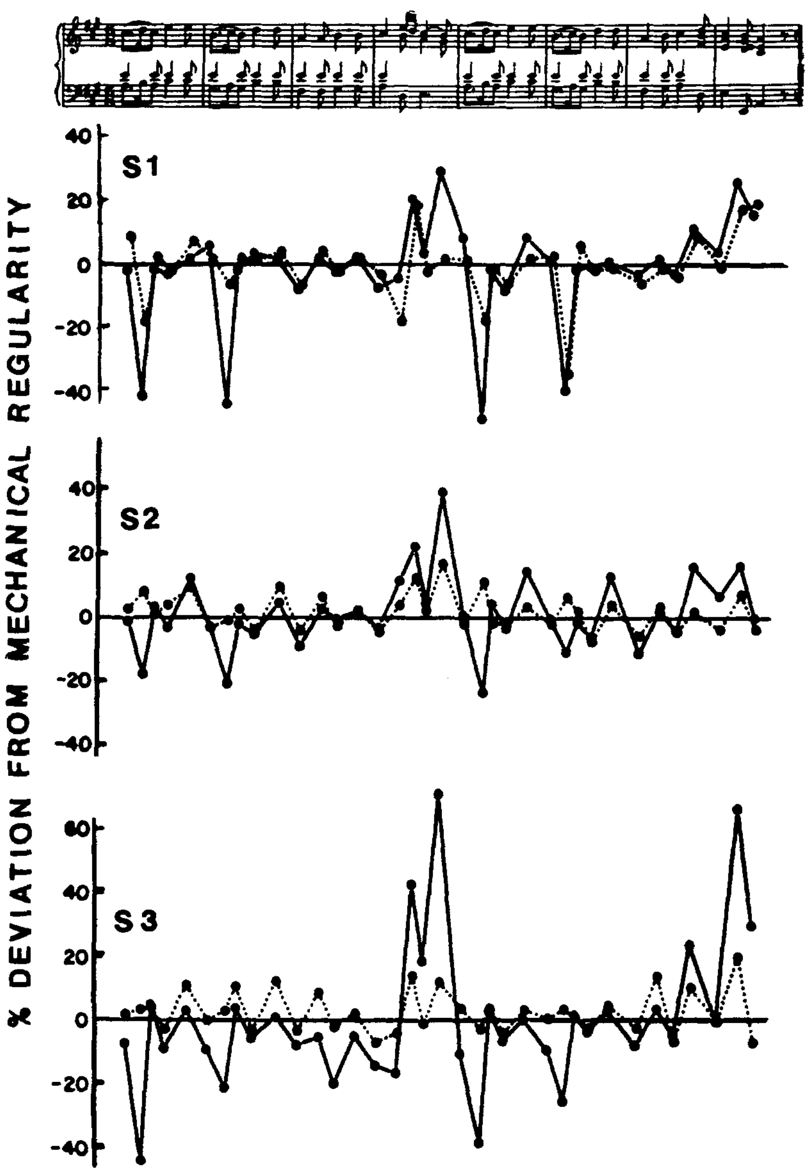

Figure 3. Experiment 1: Rubato patterns of 3 students for melody of Mozart excerpt, in percentage of deviation from mechanical regularity. (Musical performances are shown in solid lines, unmusical performances in dotted lines.)

an eighth-note as 2, a quarter note as 4, etc.). An additive regression model was fit, predicting the overlap from the coded note durations. The fits of the regression model were calculated separately for the two styles, staccato and legato, averaged across performers using that style. The additive model provided a good fit for both the staccato ($R = .65$, $p < .05$) and legato ($RF = .61$, $p < .05$) performances. The note duration preceding the overlap had the largest contribution to the two models, reflected in the standardized regression coefficients for staccato (preceding note coefficient = −.54, $p < .05$; following note coefficient = −.61, $p < .05$) and legato (preceding note coefficient = −.52, $p < .05$; following note coefficient = .18, $p > .20$) performances. Generally, as the note duration preceding the overlap increased, the amount of overlap decreased.

The fit of the regression model on an individual basis was significant for 4 of the 6 performers; the 2 performers for whom the model was not appropriate were the student specializing in this style (who used mainly staccato), and the expert specializing in 20th century music (who used mainly legato). Other regression models including an interaction term were compared for these two performers; no other regression model based on the surrounding note durations provided a better fit.

Exaggerated performance. To further demonstrate that the extent to which the three patterns occur is directly related

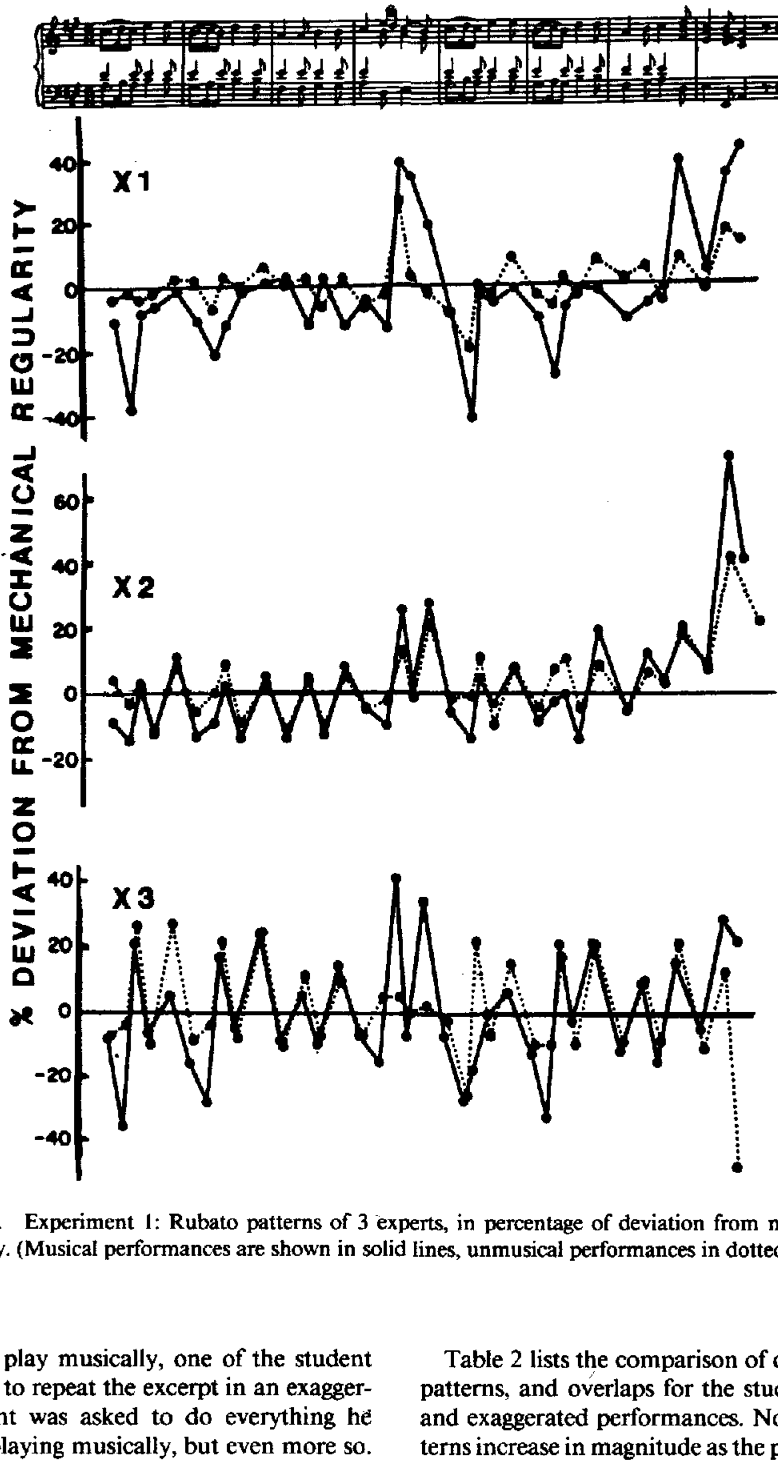

Figure 4. Experiment 1: Rubato patterns of 3 experts, in percentage of deviation from mechanical regularity. (Musical performances are shown in solid lines, unmusical performances in dotted lines.)

to the pianist's intent to play musically, one of the student musicians (S2) was asked to repeat the excerpt in an exaggerated fashion. The student was asked to do everything he considered to be part of playing musically, but even more so. If the three timing patterns are applied in a graded manner through alteration of motor parameters, then the exaggerated performance ought to show greater amounts of chord asynchrony, rubato, and overlap patterns than seen in the normal musical performance. Alternatively, if the timing patterns are not parameterized but instead are applied in an on–off fashion, then the exaggerated performance ought to show asynchronies, rubato, and overlaps not different from those in the musical performance.

Table 2 lists the comparison of chord asynchronies, rubato patterns, and overlaps for the student's unmusical, musical, and exaggerated performances. Not only do each of the patterns increase in magnitude as the performances become more "musical," but the rubato patterns retain the same overall contour; the same directionality of tempo change was applied to the same locations in the musical excerpt, as reflected in the correlations between performances.

Discussion

The three timing patterns: chord asynchronies, rubato patterns, and overlaps, were found in each of six musical per-

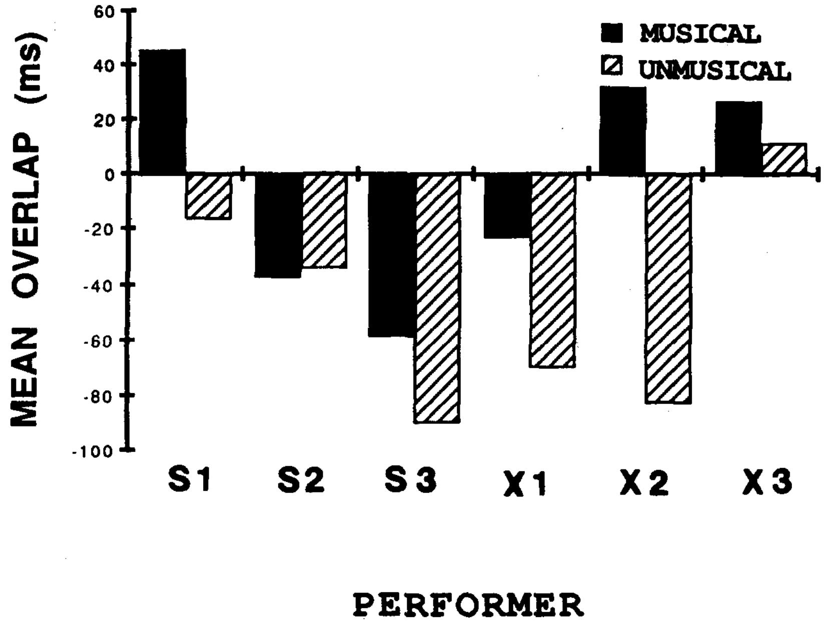

Figure 5. Experiment 1: Mean overlaps in melody for musical (black) and unmusical (shaded) performances.

formances and to a lesser degree in six unmusical performances from the same performers. Chord asynchronies were found such that the melodic notes preceded other notes in each chord. Rubato patterns were present such that tempo changes were greatest at phrase boundaries. Overlap patterns were used such that legato and staccato patterns were proportional to the durations of surrounding notes within the melody. Each of these patterns may add to the perceptual salience of the musical structure by separating melody or primary musical lines from accompaniment and accentuating phrase boundaries. Although these patterns only describe some of the variation in piano performance style, they provide a basis for analyzing the interpretive style of a performer and for comparing the style of one performer with another.

Table 2
Comparisons between Unmusical, Musical, and Exaggerated Performances by Student Musician

Measure	Unmusical	Musical	Exaggerated
Asynchrony–melody lead (M)	15.88	17.31	26.19*
Rubato (SD)	0.06	0.12	0.19*
Overlap–melody (M)	−34.02	−37.35	22.07*

Rubato patterns	r
Unmusical–exaggerated	.15
Musical–unmusical	.42*
Musical–exaggerated	.75*

Note. Asynchrony, $df = 25$; rubato, $df = 35$; and overlap, $df = 27$. Paired t tests were conducted on a note-by-note basis for exaggerated performance with each of musical and unmusical performances; p values were corrected for number of tests. For rubato patterns, correlations are Pearson product–moment correlations.
* $p < .05$.

Correlations between successive performances by each performer indicated a high degree of consistency for each of the three patterns. The differences between musical and unmusical performances demonstrated a good degree of voluntary control, although some effect of the first two patterns still existed in the unmusical performances. The experimental context probably did not allow sufficient practice of unmusical performance to fully test the degree of voluntary control. The amount of chord asynchrony and rubato in the musical and unmusical performances do correspond respectively to perceptible and imperceptible differences found for judgments of nonmusical temporal events (Hirsh, 1959; Woodrow, 1951). The use of the same methods in unmusical, musical, and exaggerated performances (to varying degrees) supports a parameter theory of motor programs in which the same procedures are repeated with altered parameters rather than the procedures being altered from one performance to another. Finally, there were individual differences in the methods that depended on both overall experience and styles of specialization, which suggests that the methods' application may depend in part on individual as well as compositional style.

There are several features of this particular musical excerpt that could account for the presence of these methods, which may not be general procedures for accentuating a melodic or phrasing structure at all. One potential problem for chord asynchronies is that the melodic voice in the Mozart excerpt is always the highest frequency in each chord and the rightmost event on the keyboard (played by the right hand). It follows that frequency location or hand, rather than melodic line, may have determined asynchronies. The amount of rubato, rather than being determined by phrasing, may have been determined by the major metrical events; the excerpt included two symmetric four-measure phrases, both of which coincided with metrical structures. (Each phrase was composed of exactly four measures.) The use of rubato may be more clearly studied with an excerpt in which phrasing and metrical structures do not coincide. Use of overlaps may also depend on location of melody or phrasing and metrical coincidences. Finally, the differences due to individual pianists' stylistic specialization suggest that the three timing methods may differ in magnitude or in relationship to the musical score from one musical period to another, perhaps parallelling compositional changes in musical structure and interpretation.

A second experiment was conducted to address these questions by (a) choosing an excerpt in which the melody changes in frequency and hand position relative to the other notes in each chord, (b) using a musical excerpt with more ambiguous musical structure from a different historical period, and (c) collecting information on the intended interpretations of the performers. If the patterns are used as methods for aiding a listener to perceive musical structure, particularly when the notated structure is ambiguous, then the use of the patterns ought to correspond to the performers' intended structural content.

Experiment 2: Effects of Performers' Interpretations

The goal of the second experiment was to map the timing patterns described in the first experiment to the performers' specific interpretations. To test the hypothesis that the timing methods are used to communicate interpreted structure, the performers in this study were asked to notate their musical interpretations in terms of melody and phrasing, the features hypothesized in the first experiment to affect performance timing.

Eight pianists were invited to perform the opening section of a piano intermezzo by Brahms (shown in Figure 6), an excerpt representative of the Romantic period of composition. Several features of this excerpt differ from the Mozart excerpt. First, the texture is thicker (more simultaneous voices contribute to each chord); this allows a more stringent test of chord asynchronies. Second, the melody weaves in and out of the upper and middle voices; this allows a test of the hypothesis that the chord asynchronies in the Mozart excerpt may have been the result of a rule which applies to the uppermost voice or hand position. Third, the excerpt is longer than the Mozart excerpt; this allows the measurement of several successive phrases and analysis of corresponding rubato patterns. Finally, the choice of possible melodic lines and phrase boundaries is not as obvious in the present excerpt as in the Classical excerpt; together with the pianists' interpretations, this allows a more robust test of the idea that performers use timing to communicate particular aspects of their interpretations.

The performers were asked to notate their interpretations on an unedited musical score after playing the excerpt. (Performer S2's notation is shown in Figure 6.) The interpretations included notation of phrasing, melodic and harmonic lines, and dynamic markings, along with a verbal description of their intentions (which included emotional expression). If the performance methods directly expressed the pianists' interpretations, then the presence of the three methods ought to correspond with these notations. Specifically, the chord asynchronies ought to correspond to the notated melody, so that the melody precedes the other voices; the rubato patterns ought to correspond to the notated phrasing; and the overlaps may correspond to both the notated melody and phrasing.

Method

Subjects. Eight pianists from the Ithaca community were invited to perform the first 16 measures of the Piano Intermezzo in E-flat Major by Brahms, Opus 117, No. 1. None of the pianists had participated in the first experiment. Four were professional musicians, and 4 were student musicians. The professional musicians had between 18 and 40 years of experience performing in public and 22 to 28 years of experience teaching private instruction. The students had 13 to 28 years of private instruction on piano. Each of the pianists had previously performed the excerpt, and all were familiar with other keyboard instruments. Four of the pianists (2 students and 2 professionals) had some familiarity with synthesizers. Again, the division of pianists into students and experts was based on concertizing and teaching experience and on whether they were currently under private tutelage.

Apparatus. The pianists performed the excerpt on the same equipment as in Experiment 1, with the exception of the audio equipment. Sound was passed from a Yamaha RM1204 Mixer to a Yamaha P2150 amplifier and then to a JBL 4312A speaker set directly in front of the keyboard. The same piano timbre was used as in the first experiment, with the exception that the velocity sensitivity was set to maximum value, causing the velocity values to have higher loudness resolution.

Procedure. Pianists played the excerpt at least twice, and recordings were made until they heard the interpretation they thought satisfactory. They were then asked to notate their intended interpretation for that performance on an unedited musical score. Specifically, pianists notated what they considered to be the primary melody, phrasing, tempo changes, and dynamics for the excerpt. After completing the notation, each pianist was asked to play the excerpt unmusically (according to the same instructions as in the first experiment).

Results

A notated interpretation by one of the student pianists is shown in Figure 6. Primary melody is indicated by the circled notes, the phrasing by the slurred lines, and the dynamics and tempo changes by notations between the staves. Each of the pianists had notated multiple phrase markings and a single voice as melody. Some tempo changes were marked, and changes in dynamics were notated less frequently (primarily because of the quiet setting of the lullaby excerpt, according to the pianists). Occasionally, there was no primary melody or phrasing notated (chosen). Only those portions of the performance for which the interpretation was notated are included in the analyses below. Because the pianists did not have difficulty in defining their interpretations in these terms, the notations could be compared with each of the timing methods as measured in the interpreter's performance.

Figure 6. Experiment 2: Notated interpretation of a student musician for Brahms excerpt. (Primary melody is indicated by circled notes; phrasing, by lines above the musical score; and tempo changes and dynamics, by notation between the staves.)

Chord asynchronies. The presence of chord asynchronies in each performance was compared with the notated melody of each performer. Because the number of notes in each chord varies widely in the Brahms excerpt, the asynchrony was measured by the difference in onset times between the voice notated as melody by each performer and the remaining notes in each chord, rather than Rasch's (1979) measure of spread. The mean difference between the onset of the melody and the remaining voices did not differ significantly from 0 for the combined musical performances, $t(7) = -0.4$, $p > .70$, or for the unmusical performances, $t(7) = 0.84$, $p > .40$. The difference between melody and remaining chord was significant, however, when beat location within the measure was taken into account. Because the majority of the chords in this excerpt fell in one of four metrical positions (that is, Beats 1, 3, 4, and 6 of the measure), the asynchronies were reanalyzed by beat. The asynchronies for chords occurring on these beats are shown in Figure 7.

An analysis of variance on expertise (students and experts), instructions (musical and unmusical performances) and beat locations (Beats 1, 3, 4, and 6) resulted in a significant main effect of beat location, $F(3, 18) = 11.5$, $p < .01$, indicating that the voice notated as melody preceded the other voices most often on Beat 1 (the beginning of each measure). There was also a significant interaction between instruction and beat location, $F(3, 18) = 6.17$, $p < .01$, so that the musical performances showed a larger first beat asynchrony than the unmusical performances. Finally, there was a significant Expertise × Instruction × Beat Location interaction, $F(3, 18) = 3.44$, $p < .05$. Experts' asynchronies on the first beat were larger than those of students in the musical performances.

Individual differences were evident in the use of asynchrony between the melody and the remaining voices. One pianist applied the opposite method, that is, the melody lagged behind the other voices on average. The asynchronies for this student musician (S2) are shown in the top of Figure 8. Note that in spite of the difference in sign, the melody lags the least on Beat 1, the most highly accented position in the measure. The second individual difference was produced by one of the experts (X4), who applied greater asynchronies so that the melody preceded other voices more on Beats 1 and 4 of each measure than on remaining beats (also shown in Figure 8). This expert specialized in music of the Classical period of composition, an earlier period than the Romantic period. The accentuation of the beginning and midpoint of each measure corresponds with music-theoretic predictions of important accent points. Generally, the first beat and midbeat of a measure are considered to be highly accented positions in

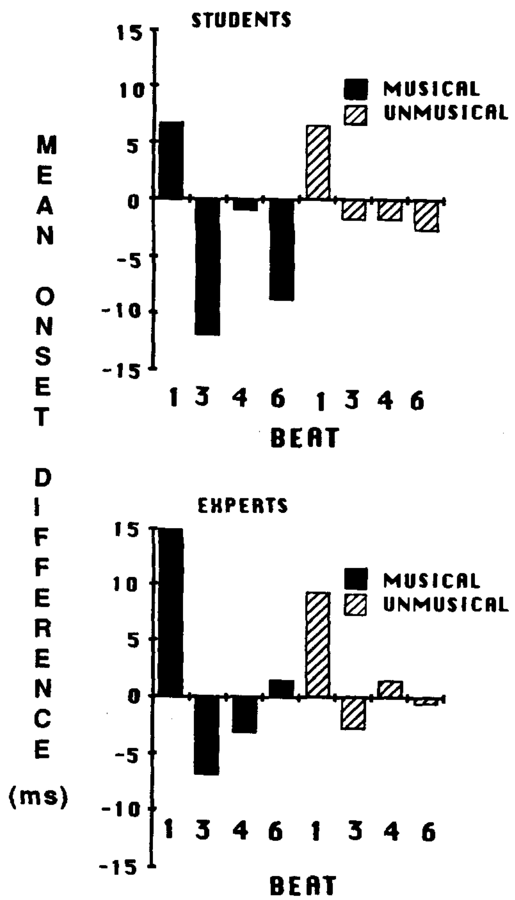

Figure 7. Experiment 2: chord asynchronies measured in mean onset difference between notated melody and remaining voices, shown by beat location. (Musical performances shown in black bars, unmusical performances in shaded bars.)

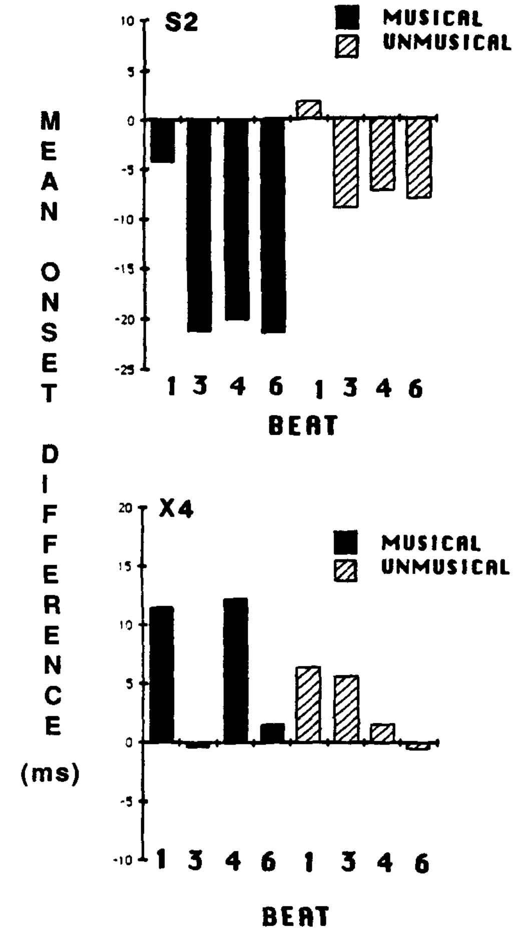

Figure 8. Experiment 2: Mean onset difference between notated melody and remaining voices by beat location for two pianists. (Musical performances shown in black bars, unmusical performances in shaded bars. Top: student musician, S2. Bottom: expert musician, X4.)

Western tonal music because they mark the beginnings of metric structures (G. W. Cooper & Meyer, 1960; Lerdahl & Jackendoff, 1983), and beat location within a measure is believed to affect accent placement in performance (Clynes, 1987).

The melodic notes may precede the remaining notes in each chord because of a performance strategy to play them sooner or a strategy to play them louder. To assess these possibilities, the temporal onset differences between melodic notes and remaining chord notes were again correlated with the velocity differences (corresponding to loudness) for each performer. Four of the 8 performers (2 students and 2 experts) showed no significant correlation between velocity and temporal onset differences, which rules out the dependence of chord asynchronies on a loudness strategy. The remaining 4 performers showed significant correlations, ranging from .48 to .70, $p < .05$, leaving the loudness strategy plausible. To test whether the effect of important beat locations on asynchronies was a consequence of performing the melody louder than the remaining notes in a chord, the analysis of variance of beat location was repeated with the effects of key velocity removed in a partial correlation. For 2 of the 4 performers (S3 and S4), the beat effect was still significant when the velocity differences were partialled out; S3, $F(5, 36) = 6.7, p < .01$; S4, $F(4, 36) = 5.01, p < .01$. This indicates that chord asynchronies showed a beat effect above and beyond the effect of key velocity. In the remaining two cases (X1 and X4) there was no significant beat effect after the effects of key velocity were removed, which suggests that the two methods (playing louder and sooner) were linked for these performances.

Rubato patterns. The second timing method, rubato patterns, was compared with the performers' notated phrasing interpretations. The rubato patterns in the excerpt's first four measures are shown for two experts' performances in Figure 9. Each performer's notated phrasing is shown above the musical score and is indicated in the graph by the gaps where the lines are discontinued.

The standard deviations of the rubato patterns were compared for the musical and unmusical performances. An analysis of variance on standard deviations by expertise (students and experts) and instructions (musical and unmusical) indicated a significant effect of instruction, $F(1, 6) = 10.2, p < .05$, with rubato greater in musical performances (average $SD = .18$) than in unmusical performances (average $SD = .11$). This was true on an individual basis for seven of the eight performers (except for 1 student). There was no significant effect of expertise or any interaction between expertise and instruction.

The large tempo changes seen in the musical performances may be used to mark phrase boundaries, as suggested by the slowing down at phrase endings in the first excerpt. If this is true, then the tempo changes ought to correspond to the performer's notated phrasing. The two phrasing interpretations shown in Figure 9 are different, and the changes in tempo are large around the notated phrase boundaries. It follows that the tempo changes at phrase boundaries ought to be larger than the tempo changes within phrases. This prediction was tested, by comparing the tempo changes within and between notated phrase markings for each performance. Tempo changes were defined as the absolute difference between adjacent values of percent deviation in rubato. Therefore, a shift from positive rubato to negative rubato, or the reverse, constitutes a large tempo change.

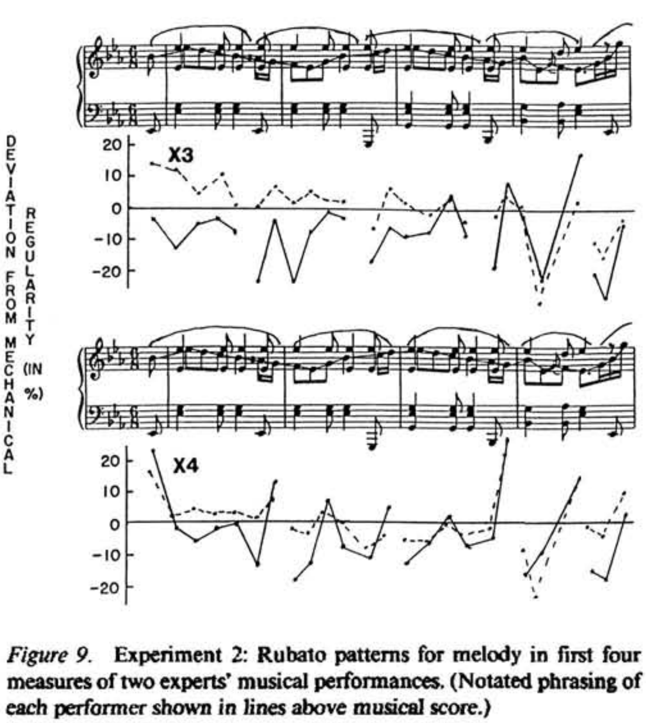

Figure 9. Experiment 2: Rubato patterns for melody in first four measures of two experts' musical performances. (Notated phrasing of each performer shown in lines above musical score.)

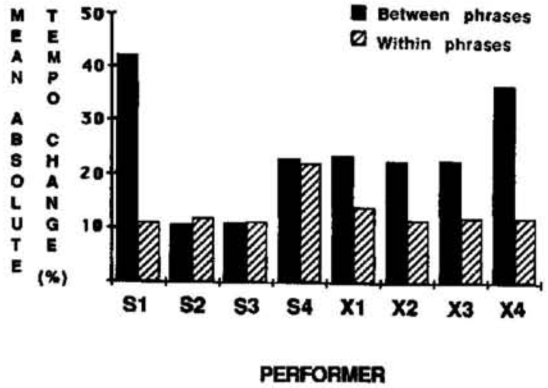

Figure 10. Experiment 2: Rubato patterns of melody in musical performances, expressed in mean absolute tempo change. (Tempo changes between notated phrase boundaries shown in black bars, tempo changes within notated phrase boundaries shown in shaded bars.)

Figure 10 shows tempo changes in the musical performances both within and between phrase boundaries, determined by each performer's notated phrasing. A Location (between–within phrase) × Instruction (musical–unmusical) × Expertise (student–expert) analysis of variance on the mean tempo changes indicated a significant main effect of instruction, $F(1, 6) = 18.4, p < .01$, in which tempo changes were larger in musical than in unmusical performances. There was also a significant Location × Instruction interaction, $F(1, 6) = 7.89, p < .05$, so that the difference between tempo changes at phrase boundaries and within phrases was larger in musical performances (mean difference = .10) than in unmusical performances (mean difference = .03). This interaction supports the hypothesis that tempo changes were used to mark phrase boundaries in accordance with the performers' notated interpretations. There was no main effect of expertise or any interactions of expertise with location or instruction.

To demonstrate that marking of phrase boundaries is directly related to the performers' structural interpretation, the two performances corresponding to Figure 9 were reanalyzed. If the rubato patterns are determined by the interpretation, then only the interpretation belonging to the original performer ought to correspond to the performed rubato changes at phrase boundaries. The two performances in Figure 9 (both by experts, X3 and X4) were chosen for this analysis because the interpretations contained the same level of explicitness and the same number of phrases, and they differed maximally in phrasing interpretations.

Figure 11 shows the reanalysis of each performance (in rows) in terms of each interpretation (in columns). A Performance (X3 vs. X4) × Interpretation (X3 vs. X4) × Location (within–between phrases) analysis of variance on the tempo changes indicated a significant main effect of location: Tempo changes tended to be larger between than within phrases. Also, there was a significant Performer × Interpreter interaction, $F(1, 64) = 5.42$, $p < .05$, indicating that tempo changes were generally larger when the performance was analyzed in terms of the performer's own interpretation. Finally, there was a significant Performer × Interpreter × Location interaction, $F(1, 64) = 8.72$, $p < .01$. When X3's rubato characteristics were reanalyzed in terms of X4's interpretation, the tempo changes were the same between and within phrases, and the same is true for X4's performance reanalyzed with X3's interpretation. Only the original performer's interpretation (shown on the cross-diagonal) characterizes the rubato patterns accurately, in that rubato changes between phrases are larger than rubato changes within phrases.

Overlaps. Overlaps between successive tones were investigated in terms of the notated melody and phrasing. If overlaps are used to create perceptual continuity in a voice by an amount proportional to the note durations in that voice, then the amount of overlaps ought to correspond to the durations of a notated voice, in this case, the melody. Because phrase boundaries typically created large discontinuities in the form of gaps or silences, the overlaps were analyzed in terms of the notated phrasing within the notated

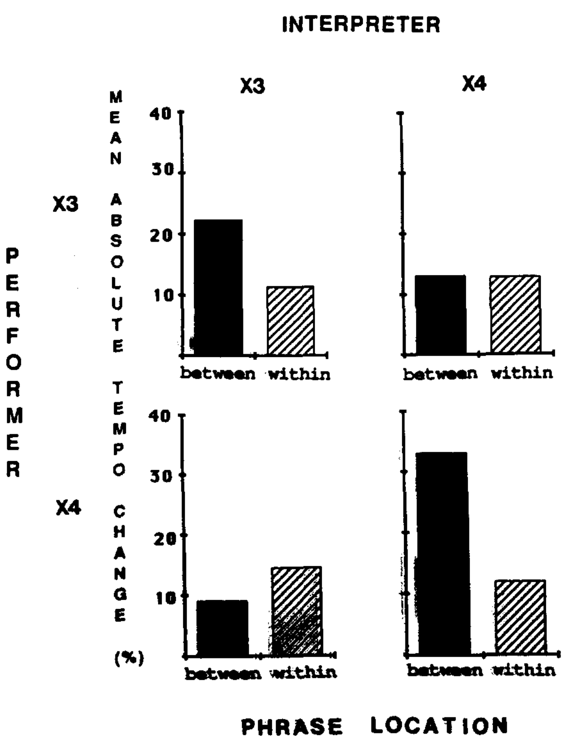

Figure 11. Experiment 2: Mean absolute tempo changes in melody between and within phrase boundaries for two experts' musical performances (shown in rows) analyzed by interpretations (shown in columns).

melody, so that notated phrase boundaries were not included in the overlap analyses. Because the damper pedal was used in some of the performances and it can be relied on to create positive overlaps even when the pianist's fingers are lifted from the keys, the overlaps are described below both with and without regard to use of damper pedal.

The mean overlap values for the notated melodies of the performers without regard to the damper pedal were negative for both musical (−57 ms) and unmusical (−113) performances, and there was no significant difference between them, $t(7) = 1.54$, $p > .16$. Five of the individual performers' mean overlaps were negative and three were positive in the musical performances. Because the damper pedal can augment or replace the use of overlaps between successive tones, the overlap values as defined here may not reflect the acoustic result. To test the role of the damper pedal, the overlaps were reanalyzed taking the pedal into account by excluding those overlaps during which the pedal was down. The adjusted overlaps did differ significantly for musical and unmusical performances, $t(7) = 2.57$, $p < .05$. As in the previous excerpt, the musical performances tended to be more legato (mean overlap = 14 ms) than the unmusical performances (mean overlap = −55 ms), which sounded more disjointed. Excluding pedaled sections of the performances, seven of the musical performances' overlaps were positive, and one was negative; each of the unmusical performances had negative overlaps. Again, there were no significant differences by expertise; instead, individual differences in the choice of legato or staccato determined the overlaps.

The relationship between the size of the overlaps and the surrounding note durations was investigated by applying a linear regression model to predict the amount of overlap. Because pianists chose to use the damper pedal in different amounts and in different locations, insufficient data for the regression analysis remained after damper pedal effects were removed; therefore, the regression analysis was based on key releases rather than damper pedal releases. The linear regression analysis, predicting the amount of overlap from the note durations preceding and following the overlap, was performed on the combined staccato performances (those performances which demonstrated average negative overlaps) and on the combined legato performances (those performances which demonstrated average positive overlaps). In each case, the surrounding note durations for the notated melody accurately predicted the amount of overlap; the fit for the staccato performances was $R = .77$ ($p < .01$), with a significant standardized coefficient for the preceding note duration (weight = −.79, $p < .01$). The fit for the legato performances was $R = .55$ ($p < .05$), with significant standardized regression coefficients for both the preceding note duration (weight = −.38, $p < .05$) and the following note duration (weight = −.31, $p < .05$). In both models the duration of the preceding note was a significant variable contributing to amount of overlap. The model fit five of the eight individual performances, and the fit approached significance ($p < .10$) for two of the remaining performances (the one remaining performance was that of a student).

To demonstrate that the overlap pattern is related specifically to the performer's interpretation (in this case, the notated melody and phrasing), two performances were reanalyzed in terms of different interpretations. Two interpretations that corresponded in phrasing but differed in melody were chosen. The interpretations that met these criteria were both by students (S1 and S2) who had used staccato or average negative overlaps. Unfortunately, the two pianists agreed for most of the piece on what the primary melody was, and therefore the comparison was made on only one quarter of the excerpt (Measures 5–8). If indeed the mapping of melodic structure to sounded performance is mediated by overlapping proportional to note durations in the melody, then the regression models should show a better fit for the performances matched with the original performer's own choice of melody.

The fits of the regression models for the two performances were calculated for each of the two notated melodies. The fit was significant only when the regression model was based on the melody of the original performer's interpretation (performer S1's overlaps with S1's interpretation, $R = .54$, $p < .10$; performer S2's overlaps with S2's interpretation, $R = .82$, $p < .01$). When performer and interpreter did not match, there was no significant fit (performer S1's overlaps with S2's interpretation, $R = .21$, $p > .60$; and performer S2's overlaps with S1's interpretation, $R = .41$, $p > .20$). This comparison further suggests that performance is directly related to the specified interpretation.

Discussion

The three timing methods corresponded in this experiment to the performers' musical interpretations of structural content. Asynchronies occurred such that the notated melody preceded the other voices; rubato patterns showed tempo changes related to notated phrasings; and overlaps were related to notated melody within notated phrases. The unique mapping of interpretation to performance was further demonstrated when one performance was reanalyzed in terms of another performer's interpretation; the timing methods were accurately characterized only when a performance was analyzed in terms of the original performer's intentions. By questioning pianists about their structural interpretations, we can successfully extract some of the variability in performance timing due to interpretation of structural content.

As in the first experiment, each of the timing methods was diminished in unmusical performances, which indicates that the mapping of structure to sound is voluntary. The poor fit of one pianist's interpretation to another pianist's performance further supports the degree of control performers have. However, the timing patterns that were strong in musical performances did not completely disappear in unmusical performances in any of the three methods, which, supported by similar findings for rubato patterns (Bengtsson & Gabrielsson, 1983; C. E. Seashore, 1938), indicates some limitations on motor flexibility.

Experts did not show larger effects of the methods than student musicians; instead, there were individual stylistic differences in how the methods were applied to communicate the performer's musical intentions. Because each student musician in this experiment was highly experienced (the average number of years of training was 17), this group may represent a level of skill acquisition too high for examining training effects. The wide range of the methods' applications in the musical performances suggests that the methods are applied in a graded manner, in order to emphasize different musical aspects, rather than being used more by expert than by student musicians.

The same methods were found in performances of the Classical excerpt of Experiment 1 and the Romantic excerpt of Experiment 2, although there were differences in application. Asynchronies were greatest on the first beat of each bar in the Romantic excerpt, accentuating the meter. This pattern was not found in the Classical excerpt; it may be that because metrical accent and phrasing coincided throughout the Classical excerpt, asynchronies were not required to accentuate the meter. In contrast, the Romantic excerpt caused different interpretations of melody and phrasing. If the Classical excerpt caused uniform interpretations of melody and phrasing, this suggests that more ambiguous material may require additional performance cues to make musical structures salient.

General Discussion

The first finding in this study was a common set of methods characterizing expressive timing in piano performances. The methods (chord asynchronies, rubato patterns, and overlaps) are part of the performer's intention to perform a piece musically. This conclusion is supported by the evidence that the application of each method decreased in unmusical performances and increased in an exaggerated performance. The second finding was the unique mapping of each performers' structural interpretation to the timing methods, evidenced by the correspondence of each method with specific aspects of the performers' notated intentions. When the timing of a performance was reanalyzed in terms of a different musical interpretation than that of the original performer, the patterns disappeared; only the original performer's interpretation characterized the methods' application accurately. The methods may be general procedures for accentuating aspects of musical structure, mapping a performer's interpretation of structural content to performance timing.

The first method, chord asynchrony, was used so that the melody (usually considered of primary musical importance) preceded other events notated as simultaneous. Although the size of the asynchronies tended to be small (20 ms), it may separate the note onsets sufficiently to make the melody perceptually salient for listeners. This reasoning, supported by perceptual evidence (Hirsh, 1959; Vernon, 1937), suggests that the amount of asynchrony may be proportional to the number of notes in a chord. This prediction was not confirmed; it is possible that small differences in chord asynchronies (falling within the range of 20–35 ms) are limited by motor constraints that prevent the precision required to separate multifinger keypresses by even smaller amounts than these.

The second method, rubato patterns, served to mark phrase boundaries so that tempo changes were largest between the end of one phrase and the beginning of another. Most performers lengthened phrase endings, similar to phrase-final lengthening in speech utterances (W. E. Cooper, 1980; Lehiste, 1972). Some performances, however, showed the opposite pattern, which indicates that the amount of change (rather than the direction of change) may signal a new musical phrase or idea.

The third method, overlap patterns, was characterized by the relationship between note offsets and subsequent note onsets. The amount of overlap was predicted from surrounding note durations for both legato and staccato performances, and the duration of the preceding note tended to contribute most to the overlap predictions. Because the overlap is proportional to the durations of preceding and following note events, it implies that planning of events occurs prior to the completion of previous events and takes into account the timing of previous events. From a motor programming perspective, the overlap regression model may reflect a fixed program with note durations as variables and with altered parameters or coefficients adjusted to determine legato or staccato. The amount of overlap was predicted only for the original performers' choice of melodic line, supporting the idea that overlaps are used to create perceptual continuity or discontinuity within a particular voice chosen for emphasis.

These findings emphasize the role of conscious intent in performance timing. One similarity between these results and other cognitive approaches to motor skills (Annett, 1985; Kelso & Wallace, 1978; Shaffer, 1980, 1981) is levels of conscious and unconscious control. Typically, motor programs for skilled performance have higher-level representations, including conscious intentions influenced by cognitive and emotional variables, and lower-level representations, including automated procedures; the procedures have parameters that are altered to meet conscious changes in task demands, but neither the parameters nor the procedures are necessarily available for conscious examination. Similarly, the pianists in this study had indirect control over the timing methods through conscious manipulation of their interpretations or musical intentions, such as choice of melody or choice of phrasing. These conscious intentions were then translated into performance timing through the primarily unconscious application of chord asynchrony, rubato, and overlap methods.

Although the methods themselves had limited accessibility to consciousness, they were sometimes generated by applying a different (conscious) strategy. For instance, most pianists were aware of the common strategy to play a melodic line louder than others but unaware that they played the melody sooner; this is consistent with other findings suggesting that performers are not always aware of whether they achieve rhythmic accents through timing or loudness (C. E. Seashore, 1938). The timing strategy was not simply a function of a loudness strategy; half of the performers used both, but most performances showed a temporal asynchrony after velocity differences were removed. In contrast, the strategy of using rubato patterns to mark phrase boundaries was recognized by all of the pianists. They were also aware of applying legato and staccato overlap patterns on different occasions and of the practical relationship between overlaps and note durations. (A note often cannot be released too late after other notes have been played, because of motor limitations such as the need to use that finger again or to reach far from that location.) However, none of the pianists were aware of the proportional relationship between the amount of overlap and the durations of the surrounding notes.

These performance methods support the idea of a rule-based system for expressive timing (Clarke, 1985; Sloboda, 1985; Todd, 1985). Both motor and syntactic systems rely on a finite set of rules for generating novel combinations; the possibility that the same rules may organize both perceptual input (such as music recognition) and productive output (such as music performance) suggests that constraints on input and output modes may be related. Specifically, the rules of performance timing described here may reflect general perceptual mechanisms for parsing acoustic material into phrases and articulated melodic lines. Some performance timing cues are successfully communicated to listeners; performed temporal changes successfully signal meter (Sloboda, 1983), and performed rubato patterns correspond to perceived and reproduced phrasing (Clarke & Baker-Short, 1987). If rule-governed systems for expression of interpretation through timing are a common form of cognitive organization, then similar systems may apply to other human communication forms such as theater, mime, and dance.

Expressive timing in music performance appears to carry information conveying a performer's interpretation of structural content. The individual differences described here, corresponding to specializations in musical period and to individual interpretations, suggest that a musical period's syntax as well as a specific syntactic interpretation may be coded in performance timing. Structural differences in music of different historical periods, as well as changes in performance practice, may result in different methods of performance timing. The research described here, however, suggests that pianists share a common set of expressive timing methods for translating musical intentions into sounded performance.

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