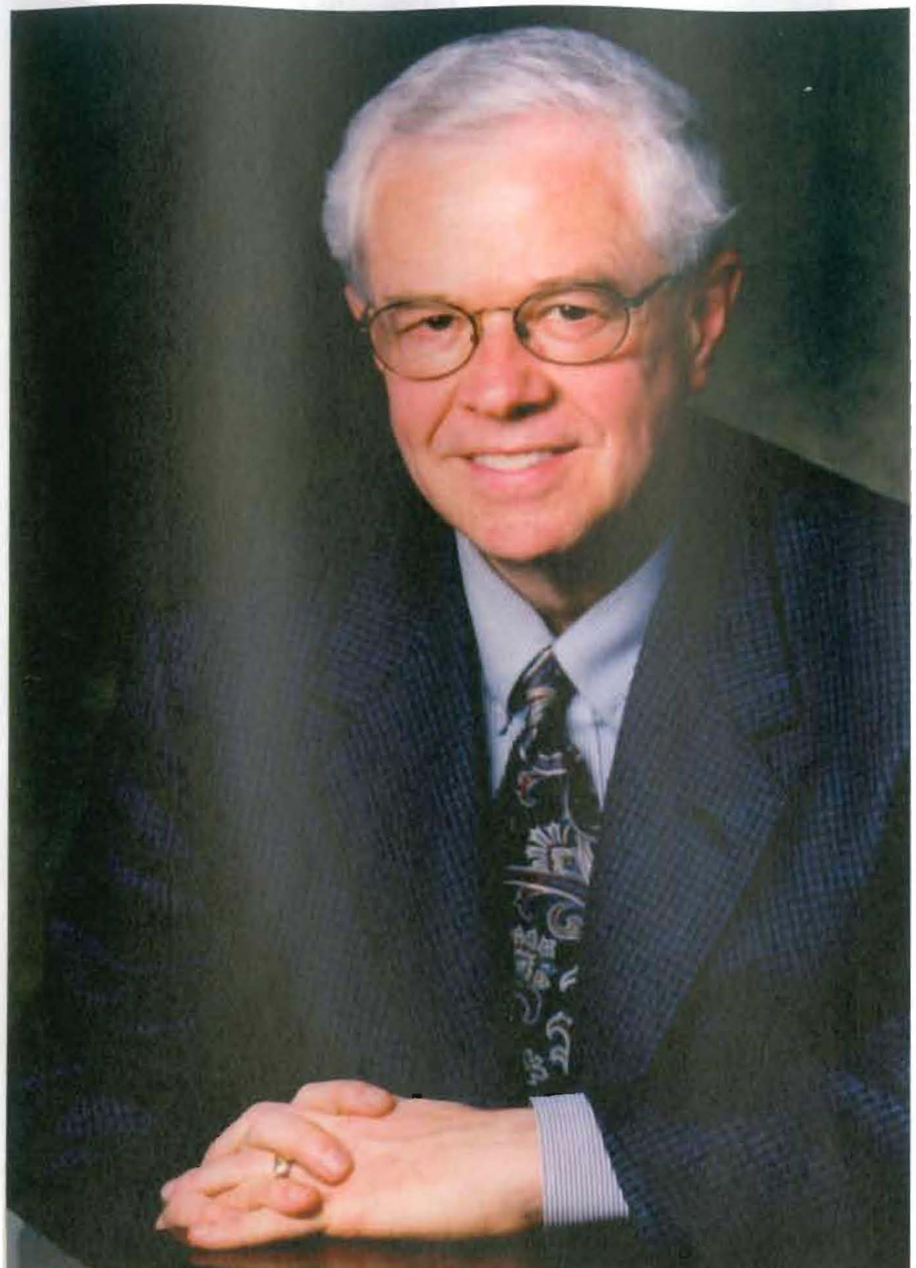

Eugene Narmour

MUSICAL IMPLICATIONS

Essays in Honor of Eugene Narmour

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Lawrence F. Bernstein
and
Alexander Rozin

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Meeting of Two Minds in Duet Piano Performance*

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Music performance requires a great deal of temporal coordination among ensemble members. Psychologists study temporal coordination—the alignment in time of actions produced by different members of a group—in various domains. For example, studies show that speakers coordinate with each other in terms of their speech rate, phoneme pronunciation, subvocal frequency/amplitude contour, and vocal intensity.[1] And partners in nonverbal coordination tasks, like swinging or rocking, often match each other in movement rates.[2] In the performance of ensemble music, the goal of producing simultaneities between different instruments or parts creates the need for strict temporal coordination. When one performer changes tempo, other ensemble performers must adjust quickly to align their sounded pitch events in time, a process that is further complicated by the fact that performers may hold to different interpretations of the same musical work.[3] Even solo works—compositions for piano, for example—necessitate high levels of temporal coordination between the two hands. In this study, we describe the simplest cases of ensemble performance: how pianists achieve temporal coordination between two musical parts when playing in solo performance (i.e., one pianist, two hands), or together in duet performance (i.e., two pianists, two hands).

We used two primary measurements to study coordination among performing musicians. The first consists in the expressive nuances that performers create in an acoustic signal: the timing of individual parts, in particular. In the performance of Western tonal music, timing is one of the most important modes of expression; tone onsets and offsets provide measures of tempo, asynchrony between parts, and articulation that characterize each

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[1]Joseph N. Cappella, "Mutual Influence in Expressive Behavior: Adult-Adult and Infant-Adult Dyadic Interaction," *Psychological Bulletin* 89.1 (1981): 101–32; Melissa K. Jungers, Caroline Palmer, and Shari R. Speer, "Time after Time: The Coordinating Influence of Tempo in Music and Speech," *Cognitive Processing* 1–2 (2002): 21–35; and Richard L. Street, "Speech Convergence and Speech Evaluation in Fact-Finding Interviews," *Human Communication Research* 11.2 (2006): 139–69.

[2]Olivier Oullier et al., "Social Coordination Dynamics: Measuring Human Bonding," *Social Neuroscience* 3.2 (2008): 178–92.

[3]Caroline Palmer, "On the Assignment of Structure in Music Performance," *MP* 14.1 (1996): 23–56.

performance.[4] L. Henry Shaffer examined the expressive timing of a four-handed duet piano performance.[5] Based on the durations of metrical bars, he concluded that the pianists most closely aligned the timing of the different musical parts at the bar level of a metrical hierarchy. The asynchronies between onsets of the simultaneously sounded parts were smaller when the same pianist was performing than when different pianists were performing, which, after all, is to be expected when the two acting limbs are controlled by the same nervous system. Less expected, though, was the fact that the pattern of asynchrony correlated across the two performers, indicating systematic causes, which Shaffer assumed were part of the musicians' interpretation of the works. However, the joint influences of musical structure, its interpretation, and motor constraints on expressive timing could not be isolated in Shaffer's analysis of a single piano duet.

The second measurement of coordination among performing musicians upon which we relied is that of motion capture, often measured through optoelectronic measurements of joint and limb movements.[6] Whereas timing is directly related to musical structure and its interpretation, the case for such a relationship for motion is less clear. François Delalande distinguished two types of motion in music performance: sound-producing motion and ancillary (non-sound-producing) gestures.[7] According to this distinction, some motions may carry important information related to interpretation in music performance. For example, clarinet performance is often accompanied by ancillary gestures, from which viewers can identify the expressive intentions of a performer.[8] Other motions may be related to physiological or anatomical constraints, such as whether the performers use large or small limb movements, or how well controlled their muscle movements are. Some studies have attempted to relate the expressive timing of music performance to

[4]Alf Gabrielsson, "Music Performance," in *Psychology of Music*, ed. Diana Deutsch (New York: Academic Press, 1999), 501–76; and Caroline Palmer, "Music Performance," *Annual Review of Psychology* 48 (1997): 115–38.

[5]L. Henry Shaffer, "Timing in Solo and Duet Piano Performances," *Quarterly Journal of Experimental Psychology: Human Experimental Psychology* 36A, (1984): 577–95.

[6]Kevin C. Engel et al., "Anticipatory and Sequential Motor Control in Piano Playing," *Experimental Brain Research* 113.2 (1997): 189–99; Werner Goebl and Caroline Palmer, "Synchronization of Timing and Motion among Performing Musicians," *MP* 26.5 (2009): 427–38; and Marcelo M. Wanderley, "Quantitative Analysis of Non-Obvious Performer Gestures," in *Gesture and Sign Language in Human-Computer Interaction: Revised Papers of the International Gesture Workshop, London, April 18–20, 2001*, ed. Ipke Wachsmuth and Timo Sowa, Lecture Notes in Computer Science, vol. 2298 (Berlin: Springer-Verlag, 2002), 241–53.

[7]François Delalande, "La Gestique de Gould," in *Glenn Gould, Pluriel*, ed. Ghyslaine Guertin (Verdun, Québec: Louise Courteau, 1988), 84–111.

[8]Wanderley, "Quantitative Analysis of Non-Obvious Performer Gestures"; and Bradley W. Vines et al., "Cross-Modal Interactions in the Perception of Musical Performance," *Cognition* 101.1 (2006): 80–113.

kinematic properties of human movement.[9] The majority of studies that report simultaneous measures of timing and motion in music performance have focused on sensorimotor coordination under optimal or altered sensory feedback conditions with simplified musical materials.[10] This research indicates that some aspects of finger movements provide proprioceptive information that guides the timing of performance.[11] Overall, the range of findings suggests that some aspects of motion may be related to structural or interpretive properties of performance, whereas other movements may reflect kinematic or proprioceptive differences among performers.

In this article, we report timing and motion-capture measurements of coordination between pianists performing in solo and duet contexts. The study was designed to compare coordination of the right-hand melodic line with the left-hand accompaniment in solo and duet performance of two-part music. That is, either a single pianist played both the right-hand and left-hand parts or one pianist played the right-hand melody while a different pianist played the left-hand accompaniment. The same right-hand melodies were performed in both solo and duet performance. The objective of this standardization was to allow for the separation of the possible influences of musical structure and its interpretation from the impact of task-specific demands that can arise from multi-limb coordination.

Our study had three goals. The first was to compare the solo and duet performances, taking into account the differences that can arise when two pianists (as opposed to one) bring to bear on their performance the effects of multiple interpretations, performance styles, and motor constraints. The duet pianists were randomly chosen. We expected to see the effects of any *a priori* differences in their individual performance styles on the timing of duet performances, and, therefore, we compared performances of the melodic right-hand part as produced in the solo (two-handed) and the duet (two-pianist) performances. Similarities across solo and duet performances were taken into account by evaluating the timing and motion cues that resulted when the same pianist performed under different conditions.

[9]Johan Sundberg and Violet Verrillo, "On the Anatomy of the Retard: A Study of Timing in Music," *Journal of the Acoustical Society of America* 68.3 (1980): 772–79; and Neil Todd, "A Computational Model of Rubato," *Contemporary Music Review* 3.1 (1989): 69–88.

[10]Cf. Janeen D. Loehr and Caroline Palmer, "Sequential and Biomechanical Factors Constrain Timing and Motion in Tapping," *Journal of Motor Behavior* 41.2 (2009): 128–36; Goebl and Palmer, "Synchronization of Timing and Motion among Performing Musicians"; and Peter Q. Pfordresher and Simone Dalla Bella, "Delayed Auditory Feedback and Movement," *Journal of Experimental Psychology: Human Perception and Performance* 37.2 (2011): 566–79.

[11]Caroline Palmer et al., "Movement-Related Feedback and Temporal Accuracy in Clarinet Performance," *MP* 26.5 (2009): 439–50; and Werner Goebl and Caroline Palmer, "Tactile Feedback and Timing Accuracy in Piano Performance," *Experimental Brain Research* 186.3 (2008): 471–79.

The second goal of the study was to compare the effects of synchronizing a melodic line in the upper (right-hand) part with a lower (left-hand) accompaniment that was designed to be either relatively simple or relatively complex. Presumably, musically complex accompaniments are harder to perform and may embody different timing and motion aspects that arise from the structural differences instantiated in different hand and finger movements. Timing and motion measures were thus expected to yield differences between simple and complex accompaniments, regardless of the number of performers. Furthermore, if performers retain in memory knowledge of the left-hand requirements, then any differences between simple and complex accompaniments might persist in both the solo condition and the duet condition.

The third and final goal was to determine whether timing and motion capture measure different effects of coordination in performance. If timing directly reflects structural and interpretive relationships among the musical parts, as Shaffer suggests,[12] then one might expect to see differences in the timing measures that reflect the musical relationships between the simple and complex accompaniments. If motion capture directly measures physiological demands on performance that arise from the need to execute one or two sets of hand movements, then one might expect differences in the measures of motion between solo and duet performances—measures that reflect the demands of the actual physical task on the performer(s). The essence of our experiment, thus, is to compare the effects of musical accompaniment and the number of performers on both timing and motion measurements in order to determine if these two indices of coordination are affected by the same relationships.

Solo and duet piano performance: Methods

We examined each pianist's performance of two-handed piano duets in two performance conditions. In the solo condition, each pianist produced the right- and left-hand parts simultaneously. In the duet condition, each pianist produced the right-hand part while another pianist performed the left-hand part. The piano duets were composed for the experiment so that we could ensure that they were equally unfamiliar to all performers. Two right-hand melodies were used. Each was four measures long, and each contained two related phrases and was composed of isochronous quarter-notes that formed a regular metrical pattern. Both melodies were designed to repeat at the end of the fourth measure so as to generate a time series long enough to permit the evaluation of our hypotheses. (One melody was adapted from Goebl & Palmer.[13]) All accompaniments were designed to reinforce the metrical structure and

[12]Shaffer, "Timing in Solo and Duet Piano Performances."

[13]Goebl and Palmer, "Tactile Feedback and Timing Accuracy in Piano Performance."

not to require any major repositioning of the hands. Each melody was paired with two types of left-hand accompaniment: simple and complex. The relative complexity of the two types was governed by its content in relation to the right-hand part. Thus, the simple left-hand accompaniment contained arpeggiated chords and repeating harmonies and required few transitions in hand position or finger movements. The complex left-hand accompaniment, on the other hand, contained some scalar movement and fewer repeating harmonies and required frequent transitions in hand position and finger movements. One of the right-hand melodies with both its simple and complex accompaniments appears in Example 1.

Example 1. Simple right-hand melody performed with simple left-hand accompaniment and with complex left-hand accompaniment

The sixteen pianists who performed in the solo condition and who played the right-hand melodies in the duet condition—henceforth, referred to as "duettists"—had a mean of fourteen years of private instruction (range = 10–23), and all but one performed regularly in ensembles. One undergraduate piano performance major, who had thirteen years of private piano instruction and ensemble performing experience, and who was asked to practice the pieces prior to the experiment, performed the left-hand part throughout the duet condition. This pianist—henceforth, referred to as the "accompanist"—performed the left-hand parts throughout the experiment so that we could control the familiarity with the left-hand parts across conditions and participants.

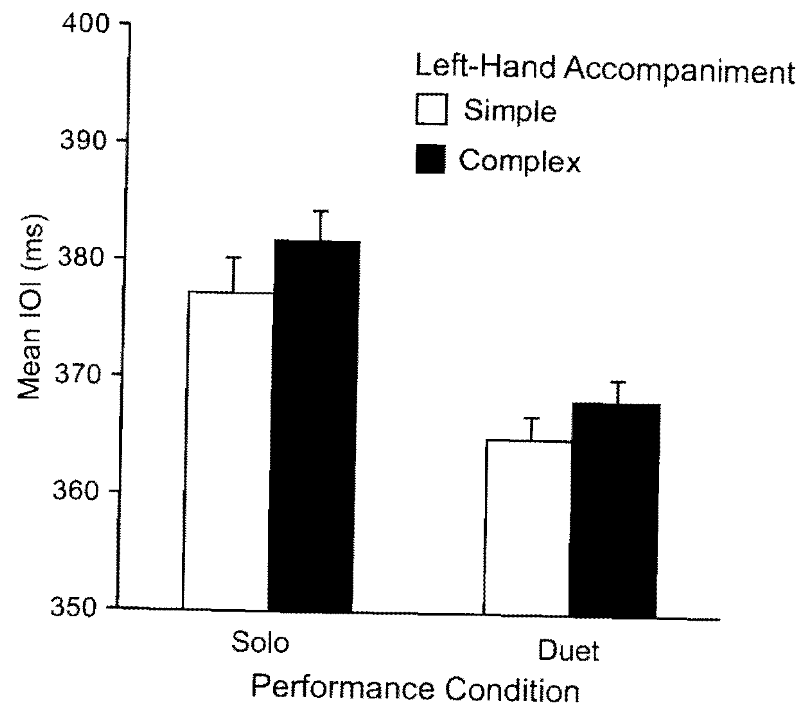
Pianists performed the music on a weighted 88-key digital piano (Roland RD-700SX, Roland Corp., USA), and their movements were recorded by a Certus Optotrak active motion-capture system. Small (3-mm) markers were taped to the pianists' fingertips and to the piano keys, and the motion was recorded at a sampling rate of 250 Hz. The pianists heard their performances, and the computer-produced metronome pacing signals, through speakers placed in front of the keyboard.

The duettists performed the conditions in the following order: first, the right-hand part alone (to become familiar with the piece), then the solo (two-handed) performances, then the duet performances (with the accompanist performing the left-hand parts). Each duettist performed each piece in the simple-accompaniment condition and in the complex-accompaniment condition. The order in which these conditions were performed was counterbalanced (reversed) across pianists in order to avoid consistent carryover effects of the accompaniment on the same right-hand melody. The solo condition preceded the duet condition to ensure that the duettists became familiar with, and had formed some interpretive representation for, the left-hand parts before performing with the accompanist. Each trial began with eight metronome clicks sounded at 400 ms intervals between tones (a moderate tempo). Pianists were instructed to begin playing the pieces after the metronome clicks ceased at the tempo set by the metronome and to perform four iterations of the piece continuously (without pause), after which time the experimenter signaled the end of the trial.

Timing measures from solo and duet performance

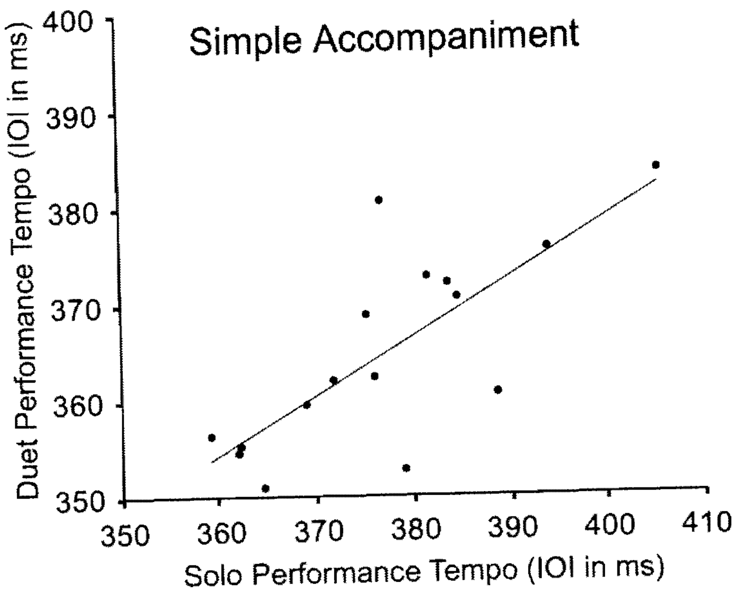
First we examined the effects of the left-hand accompaniments on the overall performance tempi. Performance was expected to be harder in the complex-accompaniment condition than in the simple-accompaniment condition, and thus we expected slower overall tempi for the complex performances. We were especially interested in whether differences in tempo would occur only in the solo performances, or if, owing to the performers' knowledge of the accompanist's part, they would also occur in the duet performances. Figure 1 shows the mean tempi, measured by the average interonset interval between tones (IOI), for the right-hand part performed in the simple and complex accompaniments in both solo and duet performances. As expected, the performance tempi for the complex accompaniments in the solo condition were slower than those for the simple accompaniments. Interestingly, the same pattern of results held in solo and duet performances. An analysis of variance (ANOVA) confirmed the main effect of the accompaniment difficulty on the mean tempo, $F(1, 15) = 6.40, p < .05$. In addition, there was a main effect of performance condition, $F(1, 15) = 39.52, p < .001$, with faster performances in the duet condition. This may have arisen from the order of conditions in the experimental design (the solo performances always preceded the duet performances, which resulted in more practice overall by the time of the duet performances). There was no interaction among these variables: the difference between simple and complex accompaniments was consistent in solo and duet performances. Thus, the difficulty of the accompaniment yielded the same kind of tempo adjustment in duet performance as in solo performance, as seen in the overall tempo of the right-hand part.

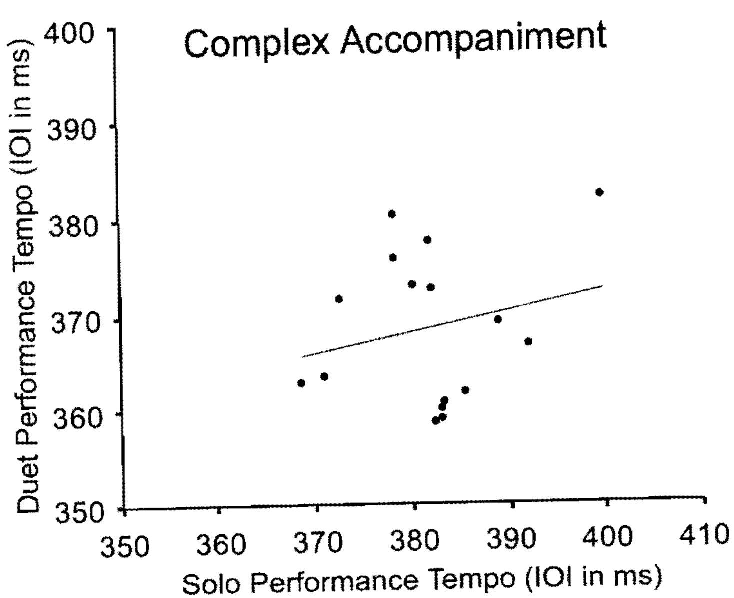
Figure 1. Mean interonset intervals (in ms) across all pianists by left-hand accompaniment (simple or complex) and performance condition (solo or duet)



We further examined the tempi at which each duettist performed the right-hand melody in the simple and complex accompaniments; the results are shown in Figure 2. The top graph, which shows the duettists' mean tempi for the simple accompaniment condition, indicates a high association between their solo and duet performance tempi ($r = .76, p < .001$). In contrast, the bottom graph, which shows the mean tempi for the complex accompaniment condition, indicates less association between their solo and duet performances ($r = .21, p > .10$). Thus, the structural relationship between the parts differentially influenced the tempi at which each duettist performed the same right-hand part. The tempo was consistent across the simple accompaniments, regardless of who was performing the left-hand part, whereas the right-hand tempo changed across performance conditions for the complex accompaniments.

Figure 2. Mean interonset intervals (in ms) for each pianist's right-hand part plotted for solo performance (x-axis) by duet performance (y-axis), with best-fitting regression line. Top graph: simple accompaniment performances. Bottom graph: complex accompaniment performances





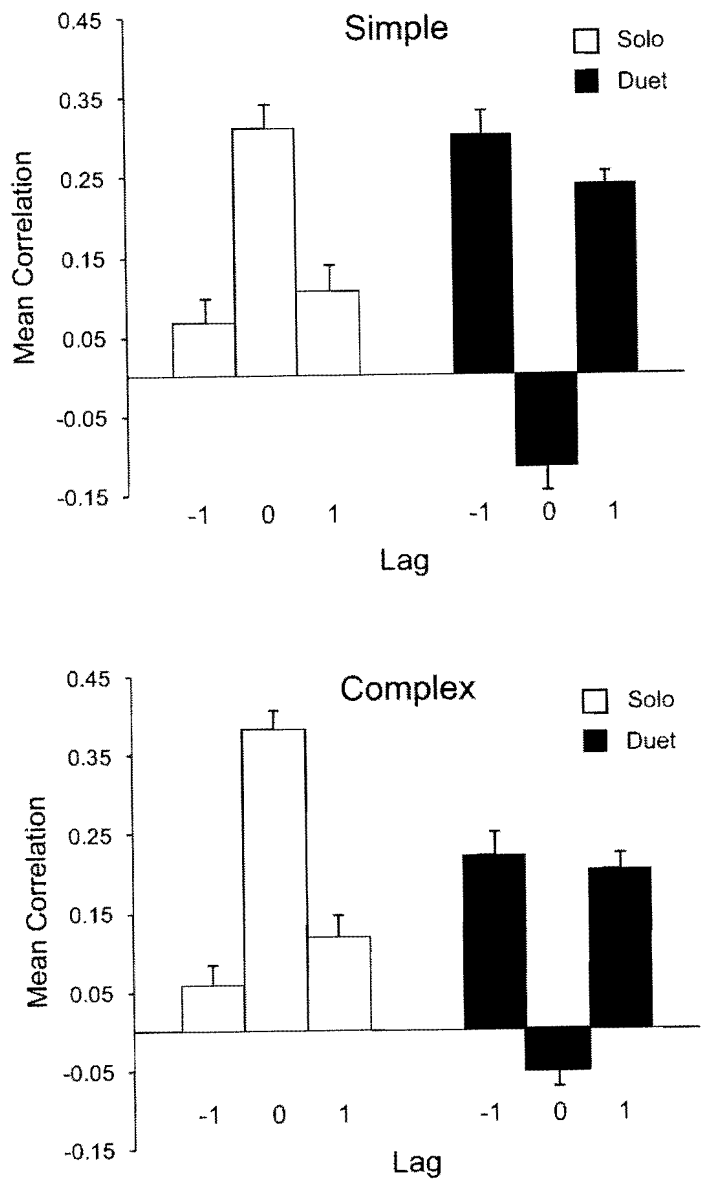
Although our primary focus is on performances of the right-hand part, performance of multivoiced music requires tempo adaptation in all musical parts. To test how the tempo of each part was adjusted, we compared the tone interonset intervals (IOIs) in each right-hand part with those generated by the left-hand part; this is referred to here as a Lag 0 cross-correlation. Positive Lag 0 correlations would be expected in solo performances (in which, of course, the same pianist plays both parts), and they would indicate a simultaneous tempo change in the same direction by each part. We compared this with a Lag -1 cross-correlation, in which the tone interonset intervals in the right-hand part are paired with those one event earlier in the left-hand part. A positive correlation at Lag -1 would indicate an influence of the left-hand tempo on the right-hand part after a delay of one tone. We also compared a Lag +1 cross-correlation (or a "lead"), in which the durations in the right-hand part are paired with those one event later in the left-hand part. A positive correlation at Lag +1 would indicate an influence of the right-hand tempo on the left-hand part after a delay of one tone. Positive Lag -1 and +1 correlations would be expected in duet performances in which one pianist changed tempo relative to another pianist, because it usually takes time for performers to perceive and adjust to another performer's tempo changes.

Figure 3 displays the cross-correlations between the timing of the left- and right-hand parts at Lags -1, 0, and +1 for the two accompaniments in the solo and duet performances. As expected, the correlations between parts in the solo performances were largest at Lag 0, indicating simultaneous interhand coordination. In contrast, the correlations in the duet performances were smallest at Lag 0 and largest at Lags -1 and +1, indicating adaptation by each performer to tempo changes in the other performer's part. An ANOVA on the cross-correlation values confirmed the significant interaction of Lag (-1, 0, +1) and performance condition: $F(2, 30) = 132.3, p < .01$. Especially important are the significant interhand correlations for both Lag +1 (when the right-hand tempo influenced the left hand after a one-tone delay), and for Lag -1 (when the left-hand tempo influenced the right hand after a one-tone delay). Such correlations may be critical for well-coordinated duet performance.[14]

In addition, there was a significant interaction of Lag with accompaniment difficulty, $F(2, 30) = 5.3, p < .05$. As shown in Figure 3, Lag 0 correlations were smaller for the simple accompaniment than for the complex accompaniment. One possible cause for this is the more primary role of the right-hand melody in the context of a simple accompaniment, which may allow the melody to stand out and vary more in notated simultaneities (what Lag 0 measures) relative to the regular pace of the accompaniment. A

[14]Goebl and Palmer, "Synchronization of Timing and Motion among Performing Musicians."

Figure 3. Mean cross-correlation between interonset intervals produced by each hand—by lag, left-hand accompaniment (simple or complex), and performance condition (solo or duet)



comparison of the absolute asynchrony (in ms) between notated simultaneities confirmed that the temporal difference in tone onsets between the right- and left-hand parts was larger in performances of the simple accompaniments than in the complex accompaniments: $F(1, 15) = 10.3$, $p < .01$, with no differences between solo and duet performances.

Measures of motion from solo and duet performance

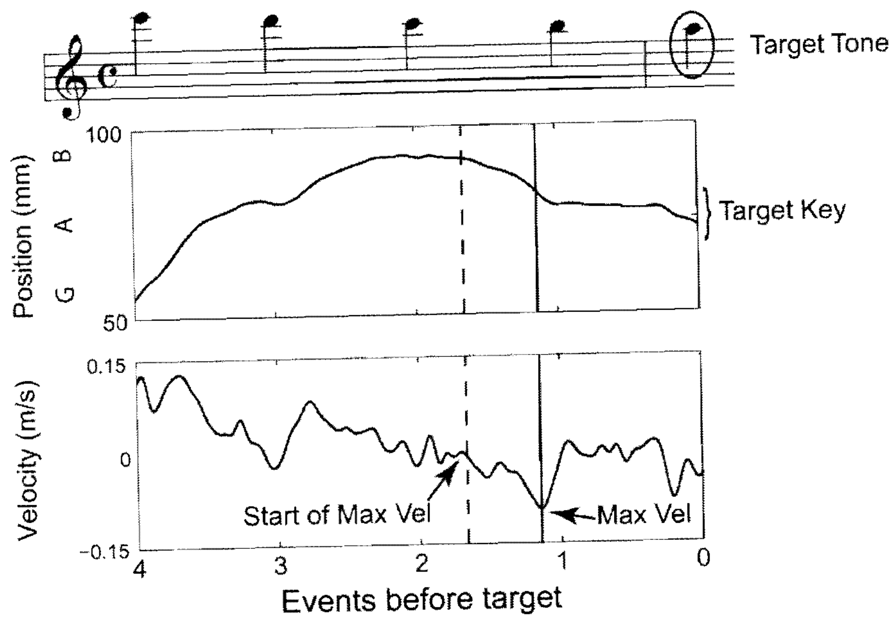
The analyses of motion focused on the movement of the pianists' fingers in the horizontal plane of the piano keyboard (left-to-right across the keyboard), as the right-hand parts required significant horizontal hand motion with change in pitch. In particular, the outer fingers (thumb and pinky) were responsible for reaching the maximal and minimal key positions (points of melodic contour change) in the pitch plane in both melodies (see Ex. 1 above). Therefore, the trajectories of motion specifically for the outer fingers were analyzed with functional data analysis techniques.[15] The data were smoothed and interpolated to create 100 equally spaced observations between the onsets of successive finger taps; the finger velocity values were aligned (co-registered) across fingers and performances in terms of the arrival time of the finger producing each tap. All analyses of the motion trajectories compared the equally spaced observations between the onsets of finger taps across performances.

The upper portion of Figure 4 demonstrates the position of finger 1 (thumb) toward the A_5 key (marked as Target Key) during the first two measures, taken from one of the performances. The vertical tick marks indicate the time at which each tone was sounded (determined by when each key was struck). The lower portion of Figure 4 indicates the velocity in meters per second (m/s) of finger 1 over the same two measures. Positive values indicate motion to the right on the keyboard, whereas negative values indicate motion to the left. Finger 1 is first pulled rightward (positive velocity), and then turns leftward along the piano plane (negative velocity) and reaches its maximum (negative) velocity, indicated by the solid line in Figure 4, prior to arrival on the A_5 key. We evaluated the velocity of finger movements in order to see how far in advance the finger started toward its goal. In doing so, we used a measure of preparatory movement similar to that employed in maze-tracing research. First, we identified the time of the finger's maximum velocity toward the key, and then we measured the time at which the finger reached 10% of that maximal velocity, which is interpreted as the onset or start of the preparatory movement.[16] An example of this measure is shown

[15]James O. Ramsay and Bernard W. Silverman, *Functional Data Analysis,* 2nd ed. (New York: Springer, 2005).

[16]Timothy A. Salthouse and Karen L. Siedlecki, "Efficiency of Route Selection as a Function of Adult Age," *Brain and Cognition* 63.3 (2007): 279–86.

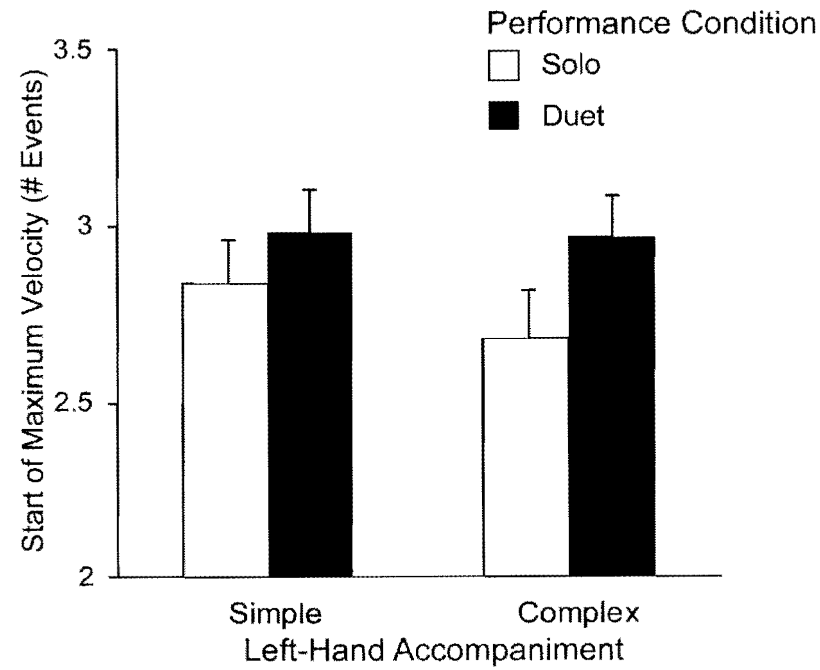
Figure 4. Example of one pianist's finger motion in horizontal keyboard plane, prior to arrival at target key. Top graph: finger 1 (thumb) position (in mm) relative to key goal. Bottom graph: finger 1 velocity (in m/s) for the same performance, with maximum finger velocity (solid vertical line) and 10% threshold of maximum velocity (dashed vertical line)



at the bottom of Figure 4. This "start of maximum velocity" (henceforth, SMV), computed in the number of pitch events prior to the finger's arrival on the target key, was expected to be earlier (larger number of events) in duet performances than in solo performances because the same performer had to prepare the motor commands for two hands in the solo but for only one hand in the duet performances. If the complex accompaniment performances are indeed more difficult, then the right-hand fingers may show shorter times of preparatory movement toward their keys later in performances of the complex accompaniments than in performances of the simple accompaniments.

Figure 5 shows the mean Start of Maximum Velocity (SMV), in number of events prior to the right-hand fingers' target keystroke, for each condition. As shown, duettists' finger movements tended to start toward their key goals earlier in the duet performances than in the solo performances; an ANOVA on the SMV measures confirmed the main effect of performance condition: F (1, 15) = 8.56, p = .01. Thus, the preparatory movements suggest that the duet performances allowed more advance preparation by the performer playing the right-hand part than did the solo performances, in which the same performer had to produce two-handed movements. The earlier preparatory motion of the right hand in the duet condition than in the solo condition was evidenced in the trajectories of both of the outer fingers (thumb and pinky) as they moved toward their target keys. The effect of left-hand accompaniment approached significance, F (1, 15) = 3.25, p = .09, owing primarily to the fact that the simple performances allowed more preparatory motion on average than the complex performances. This pattern appeared only in the solo performance (when the same pianist prepared the movements of both hands). The interaction between solo/duet performances and simple/complex accompaniments did not reach significance. Overall, the movements of duettists' right-hand fingers captured aspects of physical demands on performers that differed for solo and duet performance.

Figure 5. Mean start of maximum velocity (in number of keypress events) for the right-hand finger movements by left-hand accompaniment (simple or complex) and performance condition (solo or duet)



Discussion

We examined temporal coordination among musical parts in the contexts of solo and duet piano performances of two-part music. The structure of the accompaniment consistently affected the tempi at which pianists performed the right-hand melody part, whether it was performed in solo or duet contexts: in both performance contexts, the right-hand melody was performed more slowly when paired with a complex accompaniment than with a simple accompaniment. Patterns of tone durations and onset synchronization between the two parts indicated that duet performance reflected adjustments by both performers. Measures of motion capture yielded differences in right-hand preparatory finger movements consistent with the increased physical demands of producing two sets of finger and arm movements. These findings are consistent with a view that timing parameters of music performance convey structural interpretations and motion parameters reflect constraints specific to multi-limb coordination.

Our study attempted to regulate the influence of the left-hand part on the performance of the right-hand part in duet performances by having the same accompanist perform the left-hand part in all duet pairs. The use of a confederate is typical of psychological designs, the objective of which is to control, in a predetermined manner, the nature of the interactions to which participants are exposed. This design offers the advantages of controlling information and familiarity, but it is not without the disadvantages that arise from assuming that the confederate remains in a static state. As Susan Brennan and Joy Hanna have pointed out in experiments on conversational interactions, the use of a confederate to study adaptation is risky because confederates may not show typical patterns of adjustment compared with naïve partners.[17] It is especially risky if some kinds of adaptation, such as tempo changes, are more subject to a partner's influence than others. Ultimately, it will be necessary to compare the current findings with similar measures gathered from duettist pianists who are unfamiliar with the other performers. In fact, this is the thrust of a parallel study just completed.[18] One might expect more differences between musical parts to arise under these conditions from psychological, interpretive, or physiological distinctions among performers.

Finally, in this study, we report on two primary acoustic parameters of expressive performance: tempo change and synchronization. Many other

[17]Susan E. Brennan and Joy E. Hanna, "Partner-Specific Adaptation in Dialog," *Topics in Cognitive Science* 1.2 (2009): 274–91.

[18]Janeen D. Loehr and Caroline Palmer, "Temporal Coordination Between Performing Musicians," *Quarterly Journal of Experimental Psychology* 64.11 (2011): 2153–67.

parameters of sounded performance can be used to convey interpretations of musical structure to listeners.[19] Eugene Narmour argues that music theory and analysis should enable performers to understand how different interpretations of a musical work alter our perception of the work, including how a performer's decisions emphasize or de-emphasize compositional structures.[20] Without taking into account the cognitive constraints of listeners, a performer's interpretation can fail to be communicated as intended to listeners. Additional constraints introduced by other performers in ensembles also influence how performers convey interpretations; even performances of simple musical forms such as the short pieces described here introduce attentional, memory-based, and movement-based constraints in ensemble performance. The minimal compositional differences introduced here in the simple and complex accompaniments resulted in significant changes to the timing of both solo and duet piano performances. Thus, our findings augment Narmour's view of the interpretive process, suggesting that each performer brings a unique set of cognitive constraints to ensemble performance.

Abstract

We report a study of temporal coordination among performing musicians in solo and duet piano performance. Each pianist performed the same two-part piano music in a solo condition (one pianist, two hands) and in a duet condition (two pianists, two hands). The structure of the left-hand part was designed to be either relatively simple or complex in its melodic contour, in the required hand movements, and in its relation to the right-hand melody. Tempo and synchronization measures between parts indicated that duet performance reflected adjustment by both performers while retaining some influence of their individual tempo preferences; motion capture measurements of the right-hand fingers suggested greater preparatory constraints of coordinating two-limb movements in solo performance. The structural relationships between the musical parts influenced timing in similar ways across solo and duet performances. These findings are consistent with a

[19]See, for example, Eugene Narmour, *The Analysis and Cognition of Basic Melodic Structures: The Implication-Realization Model* (Chicago: University of Chicago Press, 1990), passim.

[20]Eugene Narmour, "On the Relationship of Analytical Theory to Performance and Interpretation," in *Explorations in Music, the Arts, and Ideas: Essays in Honor of Leonard B. Meyer*, ed. Eugene Narmour and Ruth Solie, Festschrift Series, No. 7 (Stuyvesant, N.Y.: Pendragon, 1988), 317–40; idem, "Twelve Cognitive Hypotheses for Performing Musicians," (paper presented at the 6th conference of the Society for Music Perception and Cognition, Las Vegas, Nevada, June 2003; idem, "The Psychological Ontology of the Musical Score," (paper presented at the 8th Conference of the Society for Music Perception and Cognition, Montreal, Canada, August 2007).

view that timing parameters of music performance convey structural interpretations in solo and duet performance, whereas motion parameters reveal task-specific demands of multi-limb coordination.