Musical improvisation: Multi-scaled spatiotemporal patterns of coordination

Ashley Walton (waltonal@mail.uc.edu)
Department of Psychology, 4150 Edwards 1
Cincinnati, OH 45221 USA

Michael J. Richardson (richamo@mail.uc.edu)
Department of Psychology, 4150B Edwards 1
Cincinnati, OH 45221 USA

Peter Langland-Hassan (langlapr@ucmail.uc.edu)
Department of Philosophy, 206 McMicken Hall
Cincinnati, OH 45221 USA

Anthony Chemero (chemeray@ucmail.uc.edu)
Department of Psychology, 4150B Edwards 1
Department of Philosophy, 206 McMicken Hall
Cincinnati, OH 45221 USA

Auriel Washburn (washbual@mail.uc.edu)
Department of Psychology, 4150B Edwards 1
Cincinnati, OH 45221 USA

Abstract

When jazz musicians perform an improvisational piece of music their behaviors are not fully prescribed in advance. Nonetheless their actions become so tightly coordinated and their decisions so seamlessly intertwined that the musicians behave as a single synergistic unit rather than a collection of individuals. A fundamental aspect of such musical improvisation is the bodily movement coordination that occurs among the performing musicians, with the embodied interaction of musicians both supporting and constraining musical creativity. Here we consider the ability of pairs of piano players to improvise, to spontaneously coordinate their actions with co-performers. We demonstrate the ability of the time-evolving patterns of inter-musician movement coordination as revealed by the mathematical tools of non-linear time series analyses to provide a new understanding of what potentiates the novelty of spontaneous musical action. Cross wavelet spectral analysis is applied to the musical movements of pairs of improvising pianists, a method that isolates the strength and patterning of the behavioral coordination across a range of nested time-scales. Additionally, cross-recurrence quantification analysis is applied to the series of notes produced by each musician to assess when and how often they visit the same musical states throughout the improvisation. Revealing the sophistication of the previously unexplored dynamics of movement coordination between improvising musicians is an important step towards understanding how creative musical expressions emerge from the spontaneous coordination of multiple musical bodies.

Key words: Music improvisation, self-organization, movement coordination, complex dynamical systems, multi-scale analysis

Interpersonal coordination plays a key role in the dynamics and effective outcome of musical performance. This coordination requires that musicians demonstrate a kind of "precise flexibility" with respect to both auditory structure and the patterning of their body and limb movements. That is, musical competence demands the collective synchronization of both the auditory and kinesthetic dimensions, whereby the "music-making body and the sonic traces it leaves behind" are pivotal to this co-articulation (Iyer, 2004). The dynamics of movement and force in musical performance have been widely examined experimentally, (e.g., Keller, 2012; Loehr et al., 2011; Palmer, 2013), and are known to be a primary determinant of everything from musical genres, to structures of instruments, to the musician's personal identities (Baily 1985, Dalla Bella & Palmer, 2011). These coordinative patterns are not only important with respect to musicians performing highly practiced and structured musical scores (Keller & Appel, 2010; Loehr & Palmer, 2011; Ragert et al., 2013; Palmer & Loehr, 2013), but also with regard to improvised musical performance, despite the spontaneous, unplanned melodic and temporal exploration that characterizes an improvised exchange. Previous experimental investigations, however, have only focused on individual improvisers (e.g. Norgaard, 2011; 2014; Keller et al., 2011). Yet the paradigmatic example of improvisation is a duet or jazz trio, where multiple musical bodies must spontaneously coordinate while simultaneously engaging in both musical perception and action. In such situations, musicians are engaged in a continuous negotiation–anticipating and coordinating their playing behavior without the guide of musical notation. In other words, the improvised musical performance emerges within a context of social collaboration, where the ongoing inter-musician interactions operate to construct and constrain the flow of the performance from moment-to-moment (Sawyer, 2003).

Unfortunately, the complex dynamics of improvised musical coordination are not easily isolated into components, nor can be strictly defined by content or by a particular frame of time. Musician's movements may at times involve explicit communicative signals such as a touch to the head that signals "back to the top", or eye contact and nodding of the head before or after solos. But these are just a small part of a continuous flow of information about a co-performer that supports adaptive coordination and communication across the multiple time scales of an improvised musical performance. It is for this reason that the behavioral coordination that occurs between improvising musicians is best conceptualized as *emergent,* involving the synergistic self-organization of the reciprocally defined perception and action processes that support musical play (Demos et al., 2014; Keller and Appel, 2010). The non-linear analysis time series methods of complex dynamical systems provide powerful methods for the investigation of both sonic and kinesthetic patterns at multiple time scales, and the continuous flow of information for musical perception and action. Recent applications of these methods to examine musical movements and musical structure include: fractal analysis (Demos et al., 2014; Beauvois, 2007; Hennig, 2014; Rankin et al., 2009; Ruiz et al., 2014) recurrence quantification analysis (Demos et al., 2011; Serrà, et al., 2009) and sample or Shannon entropy (Glowinski et al., 2013; Keller, et al., 2011).

Nonlinear analysis methods are ideally suited for uncovering the dynamics of improvised musical performance (Walton et al., 2015); it is expected that observing how and when stable patterns in these dynamics emerge and evolve can provide new possibilities for exploring the skill of improvisation, as well what dynamics contribute to more successful musical performance.

Method

Participants

3 pairs of musicians with 9 to 30 years of training in piano performance (*M* = 14, *SD* = 6.9) and 4 to 17 years of experience in jazz improvisation (*M* = 9, *SD* = 4.7) were recruited from the local music community as well as the University of Cincinnati's College-Conservatory of Music (CCM). Participants ranged in age from 18 to 26 years (*M* = 21, *SD* = 2.4).

Procedure and Design

Participants played standing with an Alesis Q88, 88-key semi-weighted USB/MIDI keyboard controller, directly facing one another while their movements were recorded using a Polhemus motion tracking system (at 96 samples per second). Participants were equipped with motion sensors attached to their forehead, and both their left and right forearms (positioned directly below the point where their wrist bends). Ableton Live 9.0.5 was used to record all of the MIDI key press commands and the resulting audio signal during the musical improvisation. Pairs were instructed to develop 2-minute improvised duets under visual and non-visual conditions, over different backing tracks. The visual and non-visual manipulation simply involved placing a curtain between musicians for half of the performances. There were three different backing tracks: an *ostinato*, a *swing* and a *drone* backing track. The *ostinato* backing track was a short melodic phrase consisting of the four ascending chords (Cm11; BbM7/D, EbM7#11, Fadd4) that is looped every four seconds, in 7/8 time, as opposed to the more common 4/4 time signature. The *swing* backing track is the bass line of a jazz standard used by Keller, Weber and Engel (2011), titled: "There's No Greater Love". This track has a key and tempo, as well as a bass line (i.e., chord progression) designed to support improvisation. Finally, the *drone* backing track was a pair of pitches, D and A, that were played for the entire duration of the two minutes. This track has no key or tempo and requires the musicians negotiate these structural elements with each other. At the beginning of the experiment, the musicians first performed three warm-up trials, where they individually improvised over each backing track while the other sat outside the performance room. Then together they performed two improvised duets for each visual information by backing track condition (i.e., for a total of 12 performances).

Data Analysis

Cross-wavelet spectral analysis was used to assess levels of coordination in the musician's body movements. More specifically, cross-wavelet analysis assesses coordination between two time series through spectral decomposition, and subsequent examination of the strength (coherence) and patterning (relative phase) of the coordination that occurs between participants across multiple time scales (see Grinsted et al., 2004; Issartel et al., 2006, for a more detailed introduction). The strength of coordination and the relative phase angle between two time series is assessed for shorter, ½ second and second-to-second time-scales, as well as at longer 4, 8, 12 and 16 second time-scales. For example, in *Figure 1* the level of coherence between the movements of the performers' right arms over time is denoted by color (red for high coherence, dark blue for low to no coherence) and is displayed as a function of period (in units of seconds) on the y-axis. The arrows correspond to the relative phase of the coordination. Right arrows equal in-phase coordination (the two systems are visiting the same states in perfect synchrony) and left arrows equal anti-phase coordination (the phases at which the two system are visiting the same states are in

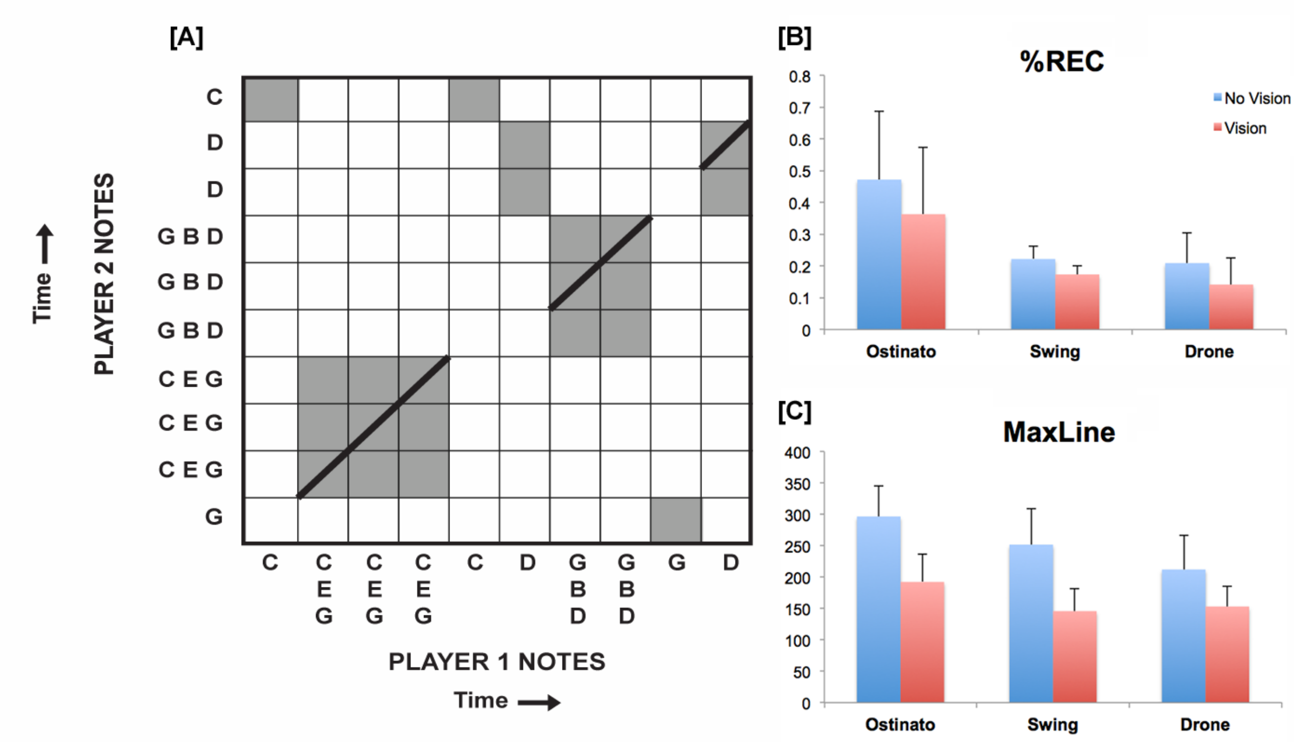

Figure 1. CRQA of the musician's musical output (i.e., notes played). **(A)** Illustrates how the times series of the notes and groups of notes (i.e. Chords) played by each musician are mapped onto one another to quantify when they are visiting the same musical states (denoted by grey boxes) and the length of the trajectories of recurrent playing behavior (denoted by black diagonal lines). The average **(B)** %REC and **(C)** MaxLine observed as a function of the three different backing tracks and "No Vision" and "Vision" conditions.

perfect opposition). This analysis was used to capture how the musician's movement coordination relates to the shorter- and longer-term temporal structure and phrasing of the musical context, as well as how this coordination varies across different parts of the musician's bodies, and the effects of the visual information manipulations.

Categorical cross recurrence quantification analysis (CRQA) was used to examine when throughout the time course of the improvised performances the musicians played the same series of notes, or visited the same musical states. CRQA is a non-linear analysis method that assesses whether the points in behavioral series visit the same states over time and then quantifies the dynamic patterns of these time-evolving recurrences using a range of different statistics (Richardson, Dale & Marsh, 2014). Two common statistics include: *Percent Recurrence* (%REC), which measures the percentage of the plot covered by the instances (dot in the recurrence plot) in which time-steps overlap and is an index of the amount of coordination present between the two instances; and *Maxline,* which extracts the longest diagonal line in the recurrence plot. As demonstrated in *Figure 1,* the time series containing the notes or groups of notes played by each musician at each time point in the improvisation were mapped onto one another in order to quantify how often they visit the same musical states through %REC.

Results

The results of the CRQA performed on the MIDI data recorded from the improvised duets are displayed in *Figure 1*. The note output from the MIDI controller provides the numbers of the keys played (from 1-88) at a rate of 96 samples/second. First the unique keys or combinations of keys played by each musician was identified, and then assigned a random code number. This time series of code numbers was then submitted to CRQA- thus the results reflect when musicians are either playing the same key or combination of keys. Differences between %REC were observed for three different backing tracks, with the musicians visiting the same musical states (notes/chords and note/chord sequences) more often for the *ostinato* backing track compared to the *swing* and *drone* backing tracks. For all three backing tracks, %REC was also found to be greater for the no-vision condition compared to the vision condition.

The results from a cross-wavelet analysis of the movement coordination that occurred between the lateral movements of the right forearms of two piano players playing with the *ostinato* backing track is shown in *Figure 2*. For comparison purposes, *Figure 2(A)* shows the results of the cross wavelet analysis when a pair was instructed to perform *in synchrony* with the backing track. There is much less coherence and stable in-phase behavior in *Figure 2(B)* which is a cross wavelet plot of the same the musicians *improvising* with one another over the ostinato track. *Figure 3(A)* shows the coordination of the musicians up-and-down head-bobbing movements, while *Figure 3(B)* shows the coordination of musicians upward and downward movements of their right hands pressing keys while improvising with the *swing* backing track. The musicians' head movements are more coordinated at the faster time scales between 0.25 and .5 seconds, where the right arm movements display coordination at the longer time scales of four seconds.

The results displayed here represent a small data set, thus it does not allow for any test of statistical significance with respective to the experimental manipulations. Future studies will incorporate larger data sets in order to evaluate hypotheses related to how movement coordination dynamics chances with the structure of the musical context (backing track) and informational coupling (vision/no vision).

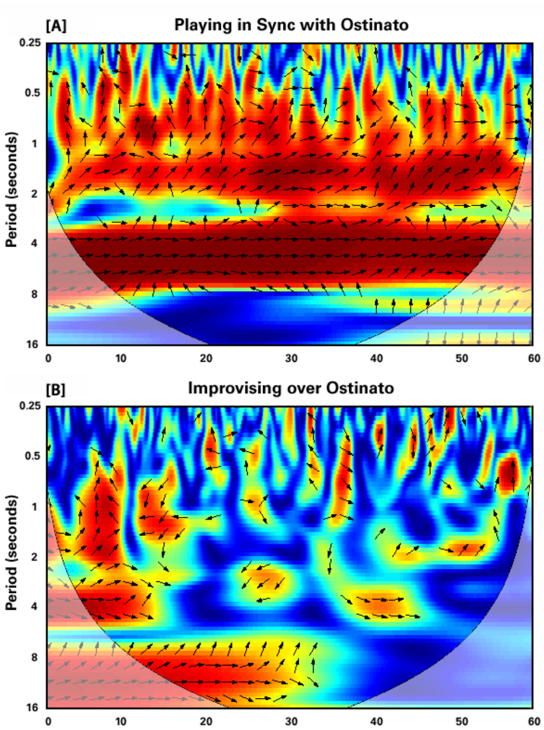

Figure 2. Cross wavelet plots of the lateral movements of the musicians' right forearms, displaying the coordination while the musicians *improvise* over the ostinato backing track **(B)** and when the two players played the exact same part, *in synchrony* with the ostinato backing track **(A)**.

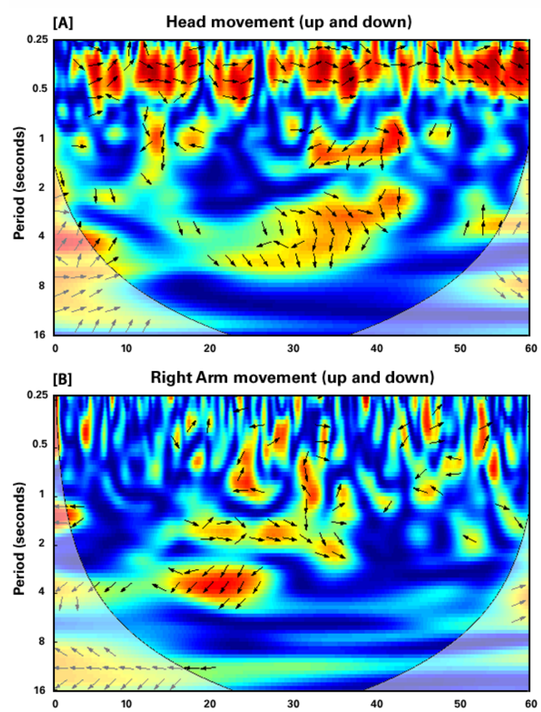

Figure 3. Cross wavelet plots displaying the coordination between two the musician's upward and downward head movements **(A)** and the coordination of the upward and downward movements of the musicians' right hands **(B)** when improvising with the *Swing* backing track.

Discussion

Three pairs of professional piano players improvised over three different backing tracks, half with visual information about their co-performer, half without, while their body movements and musical output was recorded.

For CRQA, differences between %REC and MaxLine were observed for three different backing tracks, with the musicians visiting the same musical states (notes/chords and note/chord sequences) more often for ostinato backing track compared to the swing and drone backing tracks. For all three backing tracks, %REC and MaxLine were also found to be greater for the no-vision condition compared to the vision condition, indicating that the dynamical structure of the playing behavior exhibited by musicians was less similar when they can see each other. This suggests that the improvised playing behavior of the musicians became less complex and more tightly coupled without vision in ensure a cohesive performance. In contrast, the behavioral "playing space" explored by the improvising musicians in the vision condition may have been much greater.

These results represent the power of cross-wavelet analysis with regard to determining how movement coordination relates to the shorter- and longer-term temporal structure and phrasing of the musical context. This is demonstrated through the comparison of cross-wavelet plots of the coordination that occurred between the lateral movements of pianists' right forearms when instructed to play along to the ostinato backing track together in synchrony versus improvise over the *ostinato* (*Figure 2)*. Recall that the *ostinato* backing track contains a melodic phrase consisting of four ascending chords (Cm11; BbM7/D, EbM7#11, Fadd4) that is repeated every four seconds. Accordingly, the cross-wavelet plot reveals a high degree to coherence (i.e., red) and in-phase coordination (right pointing arrows) at the four-second interval. One can observe, however, that musicians still exhibit pockets of coordinated behavior, particularly at the spectral scale (*y*-axis) of 8 to 16-second seconds. Because the 4-second melodic phrase in the ostinato track repeats four times (a total interval of sixteen seconds) this indicates that the musicians treated this as a meaningful unit-interval and transitioned to new musical phrases at divisions of this temporal unit. That is, the musicians moved their hands so they could play new keys currently out of reach at this time-scale.

Uncovering the dynamics of these spontaneous coordinative behaviors provides a way of better understanding the exchanges between order and violations of order that potentiate the novelty that characterizes improvisatory expression. Without the guide of notation, improvising musicians must be engaged in a continuous negotiation, anticipating and coordinating with changes in different aspects of each other's musical expression. This anticipatory coordination can result in dramatic transitions towards unexpected trajectories when musicians act upon information about their co-performer, as well as adapt their playing in order to re-contextualize and even take advantage of musical errors or "noise". Movement coordination is an important part of the information that can initiate these transitions to novel modes of expression: saxophonist Evan Parker claims "sometimes the body leads the imagination" (Borgo, 2005). Quantifying these spatiotemporal patterns can provide an understanding of what kinds of dynamics make possible this spontaneous emergence of previously unimagined forms of order. This not only has implications for understanding musical improvisation, but also can provide insight into the coordination dynamics at play in other creative social interactions such as joke-telling (Schmidt et al., 2014) and dancing (Washburn et al., 2014).

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