16

EMBODIED EXPRESSION THROUGH ENTRAINMENT AND CO-REPRESENTATION IN MUSICAL ENSEMBLE PERFORMANCE

Jennifer MacRitchie, Manuel Varlet, and Peter E. Keller

Introduction

In a musical ensemble, successful performance relies on being able to convey a shared notion of expression of a particular piece of music. How co-performers interact such that they generate this shared interpretation hinges on them being able to coordinate their actions both in terms of a lower, local level of discrete actions (e.g., on a note-by-note basis), as well as in higher, global levels of overall expression (e.g., coordinating global climaxes and phrase endings). Interpersonal coordination through music thus takes place at multiple spatial and temporal scales (see Figure 16.1, Panels A and B).

In general, autonomous coordination of rhythmic physical action between two or more individuals can be explained by "on-line" dynamical entrainment. However, in music, embodied expression also arises from knowledge established "off-line" prior to performance, including knowledge of the piece and performance practice traditions, familiarity with co-performers, as well as shared decisions made on interpretative aspects. In the act of performance, a vast amount of auditory and visual information is available on-line to co-performers to which they can attend, anticipate, and adapt (Keller, 2014) during a performance, confirming or updating their models (i.e., internal representations) of others' performances. Through this chapter, we consider evidence that both dynamical entrainment and co-representation contribute to successful coordination in ensemble performance.

Musical Expression

For a musician performing either by memory of a notated score, where the full structure is known a priori, or in a free improvisation, where the performer may only know a certain number of notes ahead, there is an idealized hierarchical structure of the music that considers all levels from notes that can be grouped, motifs, phrases, and sections (Clarke, 1988). Knowledge of the musical structure and musical expression are closely linked such that the structure provides the overall framework, which performers can use to inform their own interpretation, adding their expressive nuances to the music (Kopiez, 2002). This is confirmed in examining auditory features of Western classical music recordings, such as expressive timing and dynamics, where the global structure is similar, and smaller localized changes are what distinguish between performances (Repp, 1998).

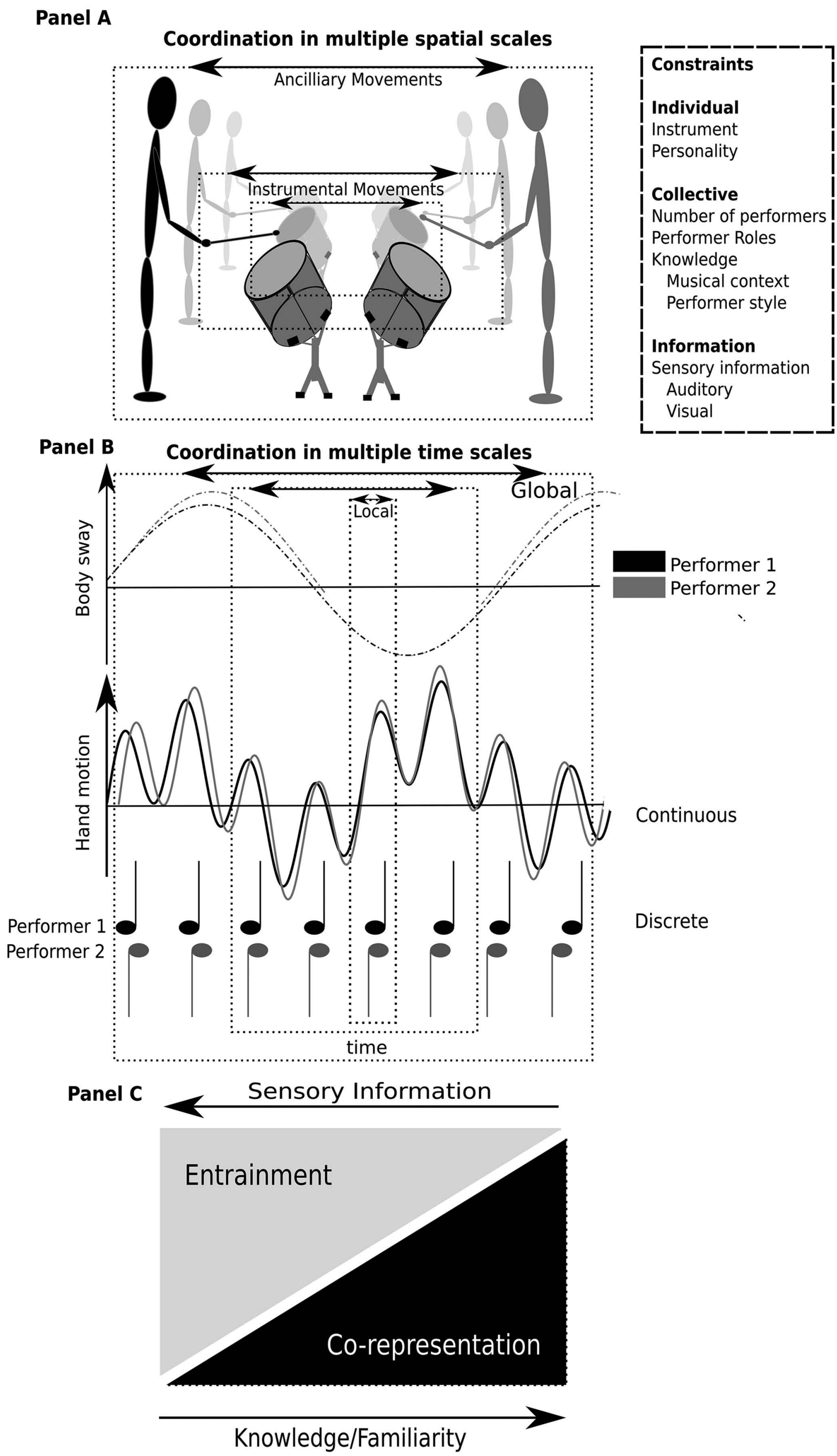

Figure 16.1 Representation of coordination at multiple spatial (Panel A) and time (Panel B) scales, acknowledging constraints that affect entrainment and co-representation processes at these scales (Panel C).

The expression conveyed by these auditory features is embodied in physical gestures (Davidson, 1993; Thompson & Luck, 2012) and facial expressions (Dahl & Friberg, 2007) accompanying a performance. Biomechanical aspects of movements required for note production and expressive gestures are integrated into a continuous stream (Davidson, 2005). These continuous movements throughout a performance are also generated from the underlying musical structure (MacRitchie, Buck, & Bailey, 2013; Vines, Wanderley, Krumhansl, Nuzzo, & Levitin, 2004), with periodicity of body sway common among performers for phrasing units, although differences in interpretation can account for small localized differences (Buck, MacRitchie, & Bailey, 2013). When performing with other co-performers, these movements have a higher regularity and so are more predictable (Glowinski, Mancini, Cowie, Camurri, Chiorri, & Doherty, 2013). Familiarity with the co-performer's part aids coordination of these continuous movements of the head and torso (Ragert, Schroeder, & Keller, 2013). Discrete gestures pertaining to specific locations in the music also have a function in ensemble performance for communicating specific information, such as marking points of local emphasis (Davidson & Correia, 2002), with the amount of discrete bodily gestures and instances of eye contact increasing with familiarity between performers (Ginsborg & King, 2009) and at particular junctures that require stricter coordination, such as tempo changes (Kawase, 2014a, 2014b).

Coordination of embodied expression in ensemble performance requires a balance between the continuous and discrete (see Figure 16.1, Panel B), managing a shared global interpretation of structure as well as certain local emphases. We consider that both entrainment and co-representation processes enable performers to maintain this balance.

Processes/Mechanisms

Entrainment

Movement synchronization between two or more individuals engaged in rhythmic activities can spontaneously emerge through dynamical entrainment (Coey, Varlet, & Richardson, 2012; Schmidt & Richardson, 2008). Entrainment is a universal phenomenon that underlies the behavioral dynamics of a large variety of biological systems, including human movement systems (Kelso, 1997; Pikovsky, Rosenblum, & Kurths, 2003; Strogatz, 2003). Dynamical system theories were originally applied to motor control in studies on intrapersonal bimanual coordination but have been extended to interpersonal coordination (Schmidt, Carello, & Turvey, 1990; Schmidt & O'Brien, 1997). Via simple and direct visual and/or auditory couplings, the movements of individuals become spontaneously coordinated such that they move together in time and space. The stronger the sensory coupling is, the greater the interpersonal synchronization (Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Schmidt, Richardson, Arsenault, & Galantucci, 2007).

Entrainment has been demonstrated in a variety of everyday situations, including people talking, applauding, walking, or running together (Néda, Ravasz, Brechet, Vicsek, & Barabási, 2000; Shockley, Santana, & Fowler, 2003; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008; Varlet & Richardson, 2015). Entrainment has also been proposed to contribute to the emergence of synchronized behavior in musical contexts (Clayton, Sager, & Will, 2005; Demos, Chaffin, & Kant, 2014; Phillips-Silver & Keller, 2012). By listening to each other, and also often watching each other, ensemble musicians are spontaneously attracted to preferred patterns of coordination that facilitate successful group performance.

Spontaneous entrainment among people is underpinned by mechanisms that are neatly captured by the Haken-Bunz-Kelso coupled oscillator model for rhythmic coordination (Haken, Kelso, & Bunz, 1985). Such coupling leads to continuous adjustments within each cycle of oscillatory processes driving movement, ensuring that movements remain synchronized between individuals. While these adjustments affect local within-cycle movement timing, a related process termed "strong anticipation" has been proposed to explain timing adjustments at a higher or more global level (Marmelat & Delignières, 2012; Stephen, Stepp, Dixon, & Turvey, 2008). Indeed, the frequency of rhythmic movements fluctuates over time. It occurs spontaneously in biological movements but can also be intentional in musical situations to fulfill expressive goals (Clarke, 1988; Gabrielsson, 2003; MacRitchie et al., 2013). Strong anticipation has been proposed to underlie a global alignment of these slow fluctuations or tempo changes, and to be independent of local adjustments at a within-cycle level (Marmelat & Delignières, 2012; Stephen et al., 2008). It is, however, currently debated whether these global and local alignments are really independent. Indeed, recent research shows that the matching of the fluctuations or tempo changes is actually only the result of local adaptations (Fine, Likens, Amazeen, & Amazeen, 2015; Torre, Varlet, & Marmelat, 2013).

In contrast to previous studies that used simple sensorimotor synchronization tasks, the independent control of local and global timing adjustments is particularly important for musicians. Specifically, musicians need to coordinate global tempo changes without interfering with local adaptations. Dynamical entrainment of musicians' continuous gestures (such as body sway), which are principally underpinned by visual couplings, may play a crucial role in matching expressiveness (see Keller, Novembre, & Loehr, 2016). Relatedly, recent evidence suggests that the entrainment of continuous gestures helps match expression at a global level and could actually help avoid interference with faster and more local timing adjustments principally underpinned by auditory couplings (Ragert et al., 2013).

Dynamical entrainment theories in motor control have been proposed, together with theories of direct perception, as an alternative to cognitive theories in motor control (Coey et al., 2012; Schmidt, Fitzpatrick, Caron, & Mergeche, 2011; Schmidt & Richardson, 2008). The principal idea behind the dynamical approach is that motor control, and thus motor synchronization of musicians, is underpinned by bottom-up processes in contrast to top-down processes advocated by cognitive approaches. On this view, the perception is direct and not mediated by mental representations. Informational couplings are sufficient to lead to the emergence of complex patterns of coordination among people—and musicians in particular. As described in the next section, however, there is evidence that local and global levels of expression are, alternatively or complementarily, controlled by more cognitive and top-down control processes.

Co-Representation

Ensemble musicians typically prepare for performance through collaborative group rehearsal aimed at establishing shared performance goals, that is, unified conceptions of the ideal ensemble sound (Keller, 2008). Establishing a shared goal involves reaching a consensus on how expressive performance parameters, including sound timing, intensity, articulation, and intonation, should be modulated in order to communicate the goal interpretation of a piece (Ginsborg, Chaffin, & Nicholson, 2006). The richness and specificity of performance goals, and the degree to which they are shared across ensemble members, vary as a function of the musical context (Keller, 2014). Shared performance goals are generally pre-planned and fixed in scripted music but arise spontaneously and transiently in improvised music.

In many musical traditions, shared goals are strategically pursued during rehearsal through a process by which ensemble musicians gain familiarity with each other's parts and the manner in which these parts will be played. This process entails acquiring knowledge about the musical structure and the expressive intentions and playing styles of ensemble members (Ginsborg et al., 2006; Williamon & Davidson, 2002). These two varieties of knowledge—structural and personal—may serve different functions and can have partially dissociable effects on ensemble coordination at different timescales. For example, a study of piano duos (Ragert et al., 2013) found that prior knowledge about the structure of a co-performer's part facilitated interpersonal coordination of ancillary body sway movements related to high-level metric units and musical phrases, while such knowledge impaired coordination at the level of keystrokes presumably because each individual produced expressive microtiming variations based on their own idiosyncratic playing style when not familiar with the co-performer's style.

Once shared performance goals are consolidated, they reside in memory as mental representations of the ideal sounds constituting a musical piece (Keller, Novembre, & Loehr, 2016). These representations embody, to varying degrees, the performer's own sound, co-performers' sounds, and the overall ensemble sound (Keller, 2008). Consistent with work on collaborative joint action more generally (Knoblich, Butterfill, & Sebanz, 2011; Sebanz, Bekkering, & Knoblich, 2006; Vesper, Butterfill, Knoblich, & Sebanz, 2010), co-performers thus come to co-represent elements of each other's parts (Keller, 2014; Loehr & Palmer, 2011).

Research using neuroscientific techniques has yielded corroborating evidence for co-existing representations of self, other, and joint action outcomes (Keller et al., 2016). A study of motor-evoked potentials elicited by transcranial magnetic stimulation (TMS: a non-invasive brain stimulation technique) during the performance of virtual piano duos indicated that representations of self and other are associated with distinct levels of excitability in the motor system (Novembre, Ticini, Schütz-Bosbach, & Keller, 2012). Another study found that using repetitive TMS to disrupt neural activity in the motor system interfered with pianists' ability to synchronize with tempo changes in recordings, but only when the pianists had formed representations of the recorded parts by practicing them beforehand (Novembre, Ticini, Schütz-Bosbach, & Keller, 2014). Finally, in a dual-EEG (electroencephalogram) study of altered auditory feedback in piano duos, Loehr, Kourtis, Vesper, Sebanz, and Knoblich (2013) identified event-related brain potentials indicating that co-performers monitored their own actions and their partner's actions in parallel while also being sensitive to the joint outcome (the harmonic relation between parts).

Co-representations of self and other may facilitate ensemble coordination by ensuring that co-performers plan to produce their parts in a manner that is mutually compatible, as well as by assisting co-performers to anticipate each other's movements and sounds via a process of action simulation (Keller, 2014). Specifically, ensemble musicians are able to plan their own actions and to simulate co-performer's actions by recruiting internal models that, through experience, come to represent transformations between motor commands and sensory experiences associated with different parts in the ensemble texture (Keller et al., 2016). In the case of music performance, these transformations link musical sounds with instrumental and ancillary body movements. Instrumental movements (such as a pianist's keystrokes) can be simulated accurately to the extent that these actions are in the observer's behavioral repertoire (e.g., when one pianist simulates another pianist). Without such specific knowledge, simulation may be limited to ancillary movements (body sway and expressive gesturing) and vocal and articulatory activity that could potentially approximate others' sounds (Keller, 2008).

Constraints on Interpersonal Coordination

Three classes of constraints affect the dynamics of interpersonal coordination: individual, collective, and informational (see Figure 16.1, Panel A).

Individual Constraints

Individual constraints on interpersonal coordination are related to movement kinematics and biomechanical properties of the effectors involved in the action in question (Schmidt & O'Brien, 1997; Schmidt & Richardson, 2008; Zamm, Pfordresher, & Palmer, 2015). It has been shown in sensorimotor synchronization tasks that different timing control processes, varying in degree of bottom-up versus top-down influence, can occur depending on the properties of the effector involved (Delignières, Lemoine, & Torre, 2004; Huys, Studenka, Rheaume, Zelaznik, & Jirsa, 2008; Spencer & Ivry, 2005; Varlet, Marin, Issartel, Schmidt, & Bardy, 2012b). An "emergent" form of timing is associated with continuous movements strongly driven by peripheral and mechanical constraints that could occur, for example, when playing a bowed instrument with legato articulation or a drum with a heavy stick at slow tempi. Here timing control is largely performed at a within-cycle level. Between-cycles control occurs with more discrete movements, such as finger strikes on a keyboard, wind instrument articulation, or drumming at fast tempi, which tend to involve an "event-based" form of timing (Torre & Balasubramaniam, 2009). Therefore, control processes involved in musical situations might depend on the type of instruments and movements involved.

Individual constraints can also operate at other levels, including the expertise of the musicians, their musical role, or their personality (Keller, 2014). In non-musical tasks, for example, social anxiety has been found to affect interpersonal coordination dynamics by degrading performance when having to lead the coordination (Varlet et al., 2014b). Musicians with high levels of empathy are particularly good at predicting the timing of co-performers' actions (Pecenka & Keller, 2011), while responsiveness to variations in this timing is correlated with the general tendency to attribute life events to internal (low adaptation) or external (high adaptation) causes (Fairhurst, Janata, & Keller, 2014).

Collective Constraints

Different roles within an ensemble can affect the type and quality of coordination that occurs among members. Leader/follower roles determine the length of gaze between co-performers, with followers gazing for longer than leaders (Kawase, 2014b), possibly to pay attention to more enhanced visual cues enacted by the leader (Goebl & Palmer, 2009). Although spontaneous emergence of leader/follower roles in brief joint tapping tasks (approximately 10 taps in length) has been characterized by frontal alpha brainwave suppression in the leader (Konvalinka et al., 2014), suggesting that they invest more planning and control resources than the follower, over longer durations (approximately 32 taps) participants mutually adapt to each other (Konvalinka, Vuust, Roepstorff, & Frith, 2010). When improvising motion in pairs in the so-called mirror game, designation of leader/follower roles for expert musicians and actors actually deteriorates the accuracy of movement synchronization (Noy, Dekel, & Alon, 2011). Analogous results have been observed in studies involving non-musicians performing with a pair of electronic music boxes (Novembre, Varlet, Muawiyath, Stevens, & Keller, 2015) where synchronization is more accurate when no leadership roles are assigned.

Complexity of the musical material can also influence the global timing of a performance both in solo and duet performances (Palmer & Loehr, 2013). The musician with the most notes (i.e., the most complex task) has been found to precede the other, and is in this sense the "leader" (Goebl & Palmer, 2009), as in joint aiming tasks where the partner with the more difficult task becomes less adaptive (Skewes, Skewes, Michael, & Konvalinka, 2015). This suggests that ensemble members can modulate their adaptability in performances with an asymmetric spread of complexity (such as in the distinction between melody and accompaniment or soloist and orchestra in a concerto) in comparison to tasks that require symmetric strategies.

The majority of empirical research on ensembles considers piano duos (e.g., Goebl & Palmer, 2009; Keller & Appel, 2010; Palmer & Loehr, 2013; Ragert et al., 2013) or string quartets (e.g., Glowinski et al., 2013), but findings can be generalized and considered to the level of small ensembles of similar instruments and sections within an orchestra. With increasing group size, distance between members will affect the coordination of their gestures, particularly if vision of other members (e.g., in a large orchestra) is restricted and/or sound is diminished. Proximity can also affect the self-to-other ratio (the degree to which an individual can hear his or her own sounds among co-performers' sounds; Ternström, 2003), which must be balanced against the need for parts to blend in terms of relative intensity. In the case of large ensembles, the role of the conductor's gestures as a focal point for co-performers is more prominent (Wöllner & Auhagen, 2008), particularly when the repertoire has a clearly defined beat (D'Ausilio et al., 2012; Luck & Toiviainen, 2006).

Informational Constraints

Informational constraints related to the flow of sensory information among performers have been found to influence the occurrence and stability of interpersonal coordination, especially when entrainment is involved. Visual and auditory couplings, and their continuity (discrete vs. continuous) in particular (Rodger & Craig, 2011; Varlet, Coey, Schmidt, & Richardson, 2012a), influence coordination dynamics, which is particularly important in relation to different sounds and movement kinematics involved with musical instruments (e.g., piano vs. violin). The amplitude and kinematics of the gestures also modulate the strength of entrainment in non-musical situations (Varlet et al., 2014a; Varlet et al., 2012a). Entrainment becomes stronger with larger movement amplitudes (Varlet et al., 2012a). The amount of visual information picked up about the observed movements also influences entrainment (Richardson et al., 2007; Schmidt et al., 2007), with central vision being associated with stronger entrainment than peripheral vision. Similarly, movement kinematics and informational constraints could affect entrainment to observed gestures in musical situations and modulate the matching of musicians' expression.

Informational constraints also affect the directionality of the couplings and adaptations among musicians. Indeed, situations where one musician cannot see and/or hear another or has only reduced information lead to uni-directional or asymmetrical couplings and adaptations (Alderisio, Bardy, & di Bernardo, 2015; D'Ausilio et al., 2012). In piano duets, reduced feedback has been shown to lead to greater head movement and designated leaders raising their fingers higher (Goebl & Palmer, 2009), as well as increased amplitude of body sway (Keller & Appel, 2010). Finally, research by Novembre et al. (2015) has shown that the pitch relation between sounds produced by two individuals playing on music boxes results in asymmetric coupling and adaptation. In this case, the individual producing low pitches exerted more influence on the high-pitch player than vice versa, consistent with the convention that bass-ranged instruments lay down the musical rhythm (Hove, Marie, Bruce, & Trainor, 2014).

Conclusion

Dynamical entrainment and co-representation both aid musicians to coordinate musical expressiveness at multiple temporal and spatial scales (see Figure 16.1, Panels A and B). Expressive information is thus conveyed at timescales ranging from a local level of discrete events (notes) to global levels where groups of notes, phrases, and sections of a piece of music unfold, as well as spatial levels ranging from small-scale instrumental movements to large-scale ancillary motion of arms, head, and body sway. The quality of interpersonal coordination within these spatial and temporal hierarchies is subject to individual, collective, and informational constraints on the processes of entrainment and co-representation (Figure 16.1, Panel A). How these processes interact in ensemble performance is an open question, with one possibility being that the balance between co-representation and entrainment (see Figure 16.1, Panel D) is influenced by a gradient describing the degree to which internal versus external information is relied upon based on the availability of knowledge about co-performer's parts (Novembre, Sammler, & Keller, 2016). In optimal scenarios, when co-performers' parts and playing styles are familiar, co-representations at the level of discrete events may provide a scaffold of mental anchor points upon which the continuous dynamics of entrainment are hung.

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