Instrumental Ensembles

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Abstract
Instrumental ensemble playing is a creative process involving real-time interpersonal coordination of sounds, gestures, and musical ideas by two or more musicians. In this chapter, we discuss the psychological mechanisms supporting ensemble coordination. Musicians' abilities to anticipate, attend, and adapt to intentional and unintentional variability in each other's playing are central to maintaining coordination during expressive performance. These abilities involve a combination of effortful and automatic processes, which musicians draw on to different degrees, depending on the musical context. Coordination is also partly supported by the affordances (action possibilities) that emerge from the evolving relationships between musicians and their physical environment. For many ensembles, offline preparation sets the groundwork for coordination in later performances, giving musicians opportunities to practice technical skills, familiarize themselves with each other's playing style, and establish shared landmarks relating to their interpretation of the music. When coordination is successful, a shared sense of togetherness emerges among ensemble musicians. Feelings of togetherness may strengthen as musicians find themselves aware and highly focused on each other's contributions to the performance, and at the same time able to coordinate seemingly without effort. Following our discussion of psychological mechanisms, we outline the implications that this research has for music education, the development of techniques to enable ensemble playing in networked conditions, and the development of technologies for musical interaction.

Keywords
Instrumental ensembles; coordination; anticipation; adaptation; attention; togetherness

Introduction

Most music is performed by groups of varying size and composition. Orchestras, chamber ensembles, rock bands, jazz ensembles, and choirs fill stages, clubs, concert halls, and venues around the world. In less formal settings, student groups rehearse for upcoming events, religious congregations sing together in worship services, community musicians participate in jam sessions, and groups of friends sing along with their favourite songs. Indeed, most people have some experience playing music with others to produce sound qualities and expressive structures that they could not create alone.

This chapter will discuss the process of instrumental ensemble performance, starting with some comments on the creative challenges facing ensemble musicians, then moving into an overview of the literature on psychological mechanisms underpinning coordination. Notably, we will distinguish between anticipatory and reactive processes, and explain how attentional strategies allow performers to move between effortful and automatic levels of coordination. Next, we will discuss how real-time "sense-making" underlies ensemble creativity, and how feelings of togetherness emerge and support ensemble playing. Finally, we will present some practical applications of this literature relating to skill development, networked performance, and technologies for musical interaction.

Goals and Challenges for Instrumental Ensembles

Ensembles face many of the same challenges as solo musicians. They have to maintain technical control during demanding passages, make expressive decisions, cope with errors and distractions, and, in the case of improvised music, generate novel musical material. On top of these challenges they must coordinate their performance as a group. *Coordination*, in this context, means producing complementary outputs that are temporally aligned[1]. Although ensembles are composed of individuals who may differ in how they want the music to sound, they must play together as a single unit.

"Playing as a single unit" can mean different things to different ensembles, depending on their musical goals. At a broad level, we can distinguish between ensembles whose goal is to perform an interpretation of notated music, ensembles whose goal is to improvise novel music within the confines of a prescribed structure, and ensembles whose goal is to improvise in the absence of a prescribed structure. An obstacle facing the first category of ensemble is the possibility that individual ensemble members will interpret the score in different ways or stray from an agreed-upon interpretation. An obstacle facing the second category of ensemble is the possibility that individual ensemble members will come up with incompatible musical ideas and struggle to respond to each other. And for the third category of ensemble, there is a risk of failing to find a point of agreement or a way to relate to each other's playing.

To generalize, we can say that all categories of ensemble face the central challenge of maintaining a desired level of coordination despite constant uncertainty about how the performance will unfold (Keller, 2014). Some uncertainty always comes from the fallibility of the human cognitive-motor system (that is, any ensemble member may make a mistake or get lost or distracted). This uncertainty is compounded by the potential for different ensemble members to make different musical decisions.

Creativity and individuality

To the extent that musical traditions value creativity in performance, musicians are encouraged to establish a playing style that distinguishes their performances from others'. The preoccupation with creativity in performance exists throughout much of the world, and is historically tied to the rise in popularity of public concerts that occurred in Europe in the 18th century (Clarke, 2012). Today, the professional music scene is crowded with highly skilled performers who are trying to distinguish themselves in order to secure commercial success.

Some musicians cope with these demands by promoting a personality which includes and extends beyond playing style, affecting also their choice of repertoire, how they design their performance environment (e.g., with visual and/or acoustic effects), and even their style of dress. For newly-formed music ensembles in particular, some negotiation between individual musicians who have spent years trying to form unique musical identities may be necessary before the group can play as a single unit.

Research concepts

Creative musical collaboration takes many forms. Musicians collaborate creatively when they discuss interpretive aspects of a piece, when they work together to write a composition, and when they explore different aspects of technique and expressivity through cycles of demonstration and imitation (e.g., during rehearsal or while teaching). These forms of

[1] Output can be temporally aligned in a multitude of ways, involving in-phase or anti-phase synchronization, intentional desynchronization, or staggering of complementary passages in time; and it may or may not occur in reference to one or more underlying meters.

collaboration occur offline. Coordinating a creative performance, on the other hand, is a real-time task (Sawyer, 2006).

The real-time nature of ensemble coordination is intriguing to researchers because it leads to questions about how people distribute their attention across multiple simultaneous functions and streams of information, and how they temporally align their own actions with others'. Ensemble performance has been described as a microcosm of social interaction, in which the ensemble functions as a dynamical system, and individual musicians function as processing units (D'Ausilio, Novembre, Fadiga, & Keller, 2015). The real-time transfer of information between musicians that is needed for the ensemble to maintain coordination and achieve their artistic goals is shaped by social dynamics and constraints relating to the musical material and instruments. In this chapter, we show how study of the interactions that unfold between ensemble musicians has been a valuable source of knowledge about how nonverbal communication, artistic expression, and social cognition.

Ensemble playing involves specific skills that musicians have to practice, that come in addition to the fundamental technical and expressive skills that have to be learned for solo playing. Musicians sometimes describe struggling to work in an ensemble setting with musicians who behave "like soloists". What makes a good ensemble player, then? The next part of this chapter will review literature on the sensory-motor and cognitive mechanisms underlying instrumental ensemble performances. This literature looks at how factors such as offline preparation, attention, and the ability to anticipate and adapt to others' playing enable successful ensemble coordination (Figure 1).

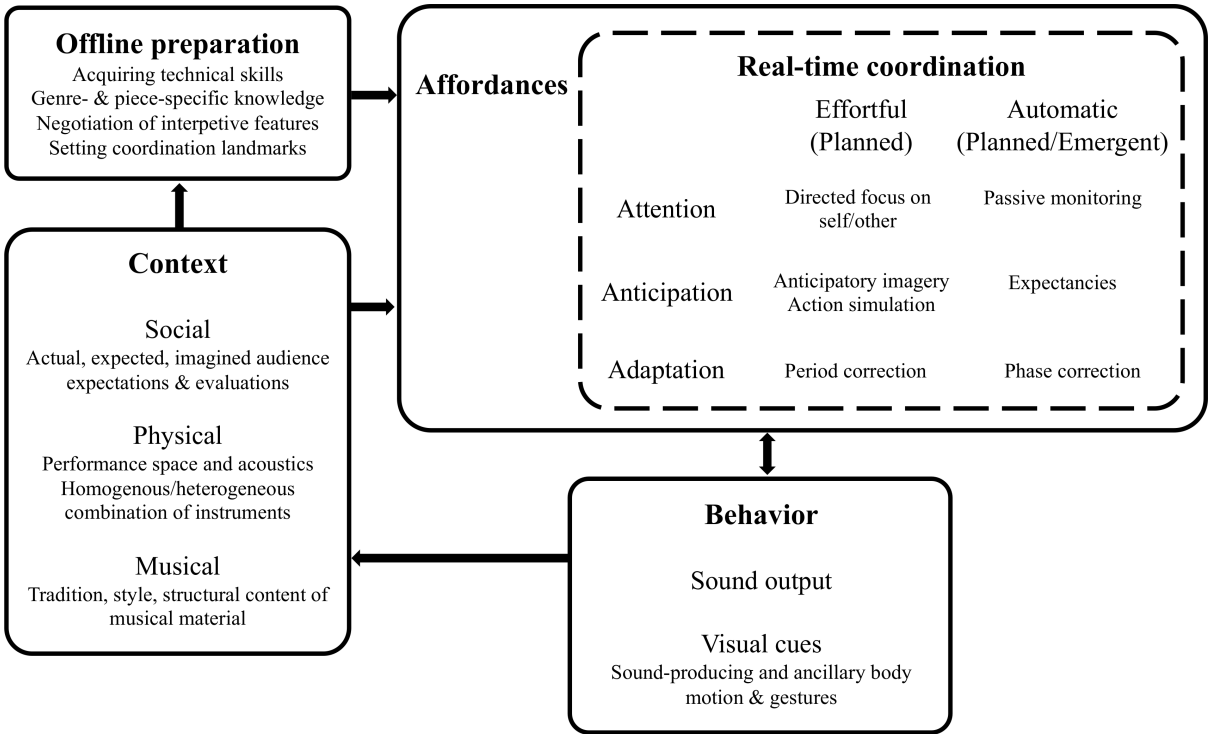

Figure 1. Basic components of the ensemble performance process. The diagram shows the relationships between offline planning, real-time coordination, ensemble behavioral output, and the social, physical, and musical environments of the performance. Real-time coordination processes are shown as occurring within the broader landscape of available affordances. The terms and concepts listed here are discussed in the text.

Psychological Mechanisms of Ensemble Coordination

Planned and emergent coordination

In the literature on ensemble performance (and more broadly, on joint action), a distinction is made between planned and emergent forms of coordination (van der Wel, Sebanz, & Knoblich, 2015). Planned coordination is intentional, which means that collaborators choose to coordinate. It involves a mixture of effortful and automatic processes, with some initially effortful processes becoming automatic after training and rehearsal, and others remaining effortful. The automatization of the processes involved in planned coordination is usually context-dependent, so processes that have become automatic during the rehearsal of a particular piece, with a particular group of co-performers, may become effortful again in the context of a new piece or new co-performers.

Planned coordination requires group members to construct covert representations of a shared goal (e.g., mental images) and their own individual contributions to that goal. In other words, they anticipate that their actions, in combination with their partners' actions, will yield certain outcomes. These anticipated outcomes help to shape group members' actions as they are carried out. Planned coordination is often aided by cueing gestures given by one of the ensemble musicians or a conductor, for example, when synchronizing the first chord of a piece. This process of exchanging cueing gestures and synchronizing note onsets can be effortful when an ensemble starts rehearsing a new piece together, but may become automatized after a period of rehearsal.

Emergent coordination occurs unintentionally as a result of perceptual-motor coupling between people (or between a group of people and their environment), which leads to similar or complementary patterns of action. Emergent coordination occurs without deliberate effort or control and draws on basic mechanisms of entrainment (spatiotemporal coupling between parts of a rhythmically moving system; see section on entrainment later in this chapter). In ensemble performance, although musicians have chosen to coordinate, they are not always in continuous control of the process, although this depends on the specific challenges presented by the music. Some musical features, such as complex polyrhythms, tempo changes, and synchronization following long pauses can require effortful (planned) coordination even if the musicians have previously rehearsed the piece.

Rehearsal and offline preparation

Offline preparation lays the groundwork for both planned and emergent forms of coordination in later performances (see Figure 1). For ensembles in many musical traditions, public performance is almost invariably preceded by some period of preparation or rehearsal. Rehearsal gives musicians an opportunity to explore different expressive possibilities and develop technical skills that can be drawn on during later performances. Some aspects of action sequences or coordination processes may be automatized during rehearsal, but ideally, performers will maintain a degree of flexibility in their playing so that they are prepared to accommodate variability and spontaneity in later performances.

It is useful to distinguish between short- and long-term preparation processes. Short-term preparation precedes public performance of specific material and unfolds over a scale of minutes, days, weeks, or months. Long-term preparation occurs over the course of months or years and generally traces the development of the relationship between ensemble members and, in some cases, also the development of their musical skills.

Studies of ensemble rehearsals at short time frames have identified three modes of inter-performer communication: instruction, cooperation, and collaboration (Seddon & Biasutti, 2009). Instruction occurs when one musician gives another specific directions regarding when or how to play, either verbally (e.g., “try playing this line more softly”) or by demonstration (playing or singing). Cooperation occurs when the ensemble negotiates basic technical and structural issues that must be resolved in order for their performance to be cohesive (e.g., discussion of bowing direction). Collaboration occurs when the ensemble negotiates creative aspects of their performance (e.g., discussion of interpretive aspects like dynamics or phrasing).

Cooperative and collaborative modes of communication are associated with different playing styles. Cooperative playing is relatively stable and predictable. Performers may draw on coordination smoothers—modulations of behavior that make actions more predictable (e.g., exaggerated gestures or breathing)—to simplify coordination. Collaborative playing, in contrast, involves creative risk-taking, although cooperative behavior such as gesturing may still play a role. During collaboration, increased “empathetic attunement” is evident in musicians' body ancillary motion, which is more communicative and demonstrates enjoyment and interest (e.g., smiling, animated body movements). Musicians' behaviour evolves as they progress through these modes of communication. Even in the course of a single rehearsal session, musicians who have not previously played together before come to show higher levels of interactivity (more body movement, more coordinated movement, more time spent watching each other; Bishop, Cancino-Chacón, & Goebl, 2019; Williamon & Davidson, 2002).

Established ensembles who have played together for years may approach their rehearsals somewhat differently than do newly-formed ensembles. Once ensemble members are familiar with each other's playing style, they may not need to communicate as explicitly as they used to. Among the few studies of rehearsal behaviour that have been conducted with established professional ensembles, there is evidence that these musicians may spend very little time watching each other (Ginsborg, 2017)—in contrast to newly formed student ensembles (e.g., Bishop, et al., submitted). Some established ensembles have been found to draw on a wider range of visual gestures than do newly formed groups, however (Ginsborg, 2017).

Affordances

Objects, events, and environments offer us possibilities for action, known as affordances. According to Gibson's (1986) ecological theory of perception, affordances are rooted in the idea that the perception and action capabilities of an animal are complementary to the physical features of their environment. Affordances are determined not by the individual or the stimulus, but by the relationship between them (Marsh, Richardson, & Schmidt, 2009). For example, a ball may afford throwing, kicking, or rolling, but it probably does not offer a good place to stand, as it might roll away.

Accordingly, we consider musical affordances to characterize the action possibilities of an environment that are defined in relation to the sensory-motor and cognitive capabilities of an individual or group. Musical collaborations are influenced by the environment—the performance space and its contents—in which they take place, and these influences emerge as a result of the changing relationship between collaborators and their environment (which itself changes as a result of the collaboration). Figure 1 shows affordances as shaped by a

combination of factors relating to offline preparation, social-physical-musical contexts, and performers' behavioral output.

When people play music, their actions are guided in part by the affordances that emerge from their relationships with their instruments and the unfolding musical material. Musicians' experience in the world helps to shape the affordances that emerge for them. For example, a piano affords a certain range of actions to a novice pianist who has relatively limited technical abilities (e.g., pressing the keys with greater or lesser force), but a greater range of actions to a practiced pianist (e.g., pressing the keys with varying touch and articulation). Our knowledge of the world also gives us the ability to recognize the affordances that exist for others.

Affordances can contribute to coordination by prompting similar actions from different people. For example, a musical piece with a fixed structure may afford the same phrasing from different people who share knowledge about that style of music and how it is traditionally played. Musicians may also mimic aspects of each other's behavior. Nonconscious mimicry is something that people do in many types of interaction, including spoken conversation, and it has been linked to increased empathy and affiliation (Overy & Molnar-Szakacs, 2009).

When people coordinate their actions, new affordances can emerge that would not have been available to individual collaborators, because groups can do things that individuals cannot. These emerging affordances might take the form of new timbres that can only be produced by a combination of instrument sounds, higher sound intensity, new harmonies, or musical dialogues that require interplay between voices.

Entrainment

Entrainment describes spatiotemporal coupling that occurs between two or more parts of a rhythmically moving system (Keller, Novembre, & Hove, 2014). People can entrain to each other unintentionally (i.e., without doing so deliberately). For instance, when people walk beside each other, they often end up going at the same pace without meaning to do so.

Entrainment can occur at a 1:1 phase ratio (e.g., the pair of walkers are stepping at the same time) or at a more complex ratio like 2:3 or 3:4 (e.g., one person is taking 2 steps in the time it takes the other person to take 3). Coupling between entrainment partners tends to be weaker when their movements form a complex ratio. Coupling strength also depends on the phase relationship between partners: in-phase synchronization tends to induce stronger entrainment than does anti-phase synchronization (e.g., playing off-beats). During ensemble performance, entrainment between musicians can manifest at the level of sound-producing movements, facilitating synchronization of note onsets, and at the level of ancillary movements (e.g., head movements) as well (Goebl & Palmer, 2009). Alignment in note timing as well as in other time-varying musical parameters such as changes in timbre or dynamics can result (Keller, 2014).

Entrainment is a low-level process that occurs automatically—it does not require people to construct intentions or mentally represent specific action goals. It is indeed such a powerful phenomenon that it can be difficult to override. Some musical works require ensemble members to resist entraining to each other by maintaining distinct rhythms or by playing the same rhythm misaligned in time (see Clapping Music by Steve Reich). Entrainment has been observed during Indian raga performance between tanpura players whose intention is to play

their rhythms independently (Clayton, 2007), and even during Afro-Brazilian Congado ceremonies, where separate groups of performers try to maintain distinct rhythms at different tempi. A group's ability to maintain rhythmic independence is meant to demonstrate their spiritual power, shown through musical cohesion (Lucas, Clayton, & Leante, 2011). In these cases, entrainment occurs at a complex level that involves multiple periodicities.

For people to entrain with each other, they must be able to perceive regularity in each other's movements (using visual and/or auditory cues), produce regular movements themselves, and integrate perceived and produced motor information using perception-action neural links. It is important to note that while entrainment partners must move regularly, it is not necessary that their movements follow isochronous rhythms. Much of the world's music uses rhythms built on isochronous beat structures, but not all—many musical traditions draw on rhythms with nonisochronous beats (including music from northern Europe, southeast Europe, parts of the Middle East, central Asia, India, and parts of Africa). Studies of ensemble performances in some of these musical traditions show that entrainment manifests predictably in note timing and body motion (Polak, London, & Jacoby, 2016).

Anticipation and adaptation

In most forms of ensemble-playing, even if the music is structured around a regular beat, deviations from strict regularity occur. Some of these deviations might be attributable to errors, but mostly they are desired for expressive effect. Expressive timing can manifest as fluctuations in global tempo (as occurs during an *accelerando* or *ritardando*) or as local phase shifts (playing a single note slightly early or late), and can affect a single voice (resulting in inter-voice asynchrony) or all voices. Ensemble musicians deal with these timing irregularities through a combination of predictive mechanisms and reactive error-correction mechanisms. In Figure 1, these mechanisms are shown as supporting both effortful and automatic forms of coordination.

Anticipation

By predicting each other's timing, musicians can plan their own actions so that their notes align with their co-performers'. Anticipation occurs at two levels, both supported by couplings between perception and action in the brain. At a low level, automatic expectancies arise in response to familiar patterns in perceived stimuli. At a higher level, effortful prediction occurs through the processes of anticipatory imagery and action simulation.

Anticipatory imagery is the process of covertly representing upcoming actions and their perceptual outcomes. Anecdotal evidence from professional musicians suggests that they use anticipatory imagery to guide their playing, including expressive aspects such as tone quality (Trusheim, 1993). This can entail imagery not only for one's own part but also for co-performers' parts and the combined ensemble output. Laboratory research has shown that pianists who have stronger anticipatory imagery abilities synchronize more successfully when playing piano duets (Keller & Appel, 2010).

Action simulation occurs when the sensorimotor brain circuits that are involved in performing a certain action are activated in the absence of overt movement (Novembre & Keller, 2014). This activation can occur as a result of seeing someone perform the action or hearing sounds associated with it. Both action simulation and anticipatory imagery are thought to draw on learned associations between actions and their perceptual outcomes. In the brain, these learned perception-action associations take the form of neural linkages that are especially strong for experienced musicians who have extensive practice with a specific

repertoire of sound-producing movements (Bishop & Goebl, 2014; Wöllner & Cañal-Bruland, 2010). Theoretical accounts hold that, during ensemble performance, these neural linkages are recruited by bi-directional *internal models*—"forward" models predict sound from motion and "inverse" models determine motion from sound—that drive simulation and imagery-based predictions about one's own part and co-performers' parts.

Skilled musicians adopt different anticipation strategies depending on the musical context, making greater use of effortful prediction when the situation requires it, and otherwise conserving their attention so that it can be focused elsewhere. Less skilled musicians may struggle to recruit anticipation processes that are appropriate for the situation, reducing their performance quality.

Adaptation

Adaptation processes allow ensemble co-performers to adjust the timing of their movements and sounds to maintain interpersonal coordination in the face of intentional and unintentional variations in performance tempo. Two types of error-correction mechanism have been hypothesized to underpin such adaptation: *phase correction* and *period correction* (van der Steen & Keller, 2013). Both mechanisms act on internal timekeepers (oscillators in the brain) that guide the timing of rhythmic actions and allow people to keep track of a regular beat. Irregularities in the performed rhythm lead to varying degrees of discrepancy in intepersonal timing that are perceived as ensemble asynchronies.

Phase correction entails small-scale local adjustments that are made to the alignment of timekeeper pulses between individuals, based proportionally on the magnitude of asynchrony between previous sounds. Phase correction is automatic and runs continuously to allow co-performers to maintain entrainment. Period correction involves adjusting the duration of the interval between timekeeper pulses. It is consciously controlled and allows people to maintain synchrony during both gradual and sudden changes in tempo.

Adaptive timing can be mutual (performers adapt similarly to each other) or asymmetrical (one performer adapts more strongly than another). Asymmetrical adaptation can occur when performers have assumed leader and follower roles, either by agreement or by default. In the latter case, if one performer has a tendency to drift, or if one performer is being uncooperative, other performers may choose to follow the less-adaptive performer in order to maintain coordination (Fairhurst, Janata, & Keller, 2014).

Attention

During ensemble performance, musicians keep track of their own playing while also monitoring others' playing and the relationship between their own part and others' parts. It is hypothesized that ensemble musicians use a type of divided attention referred to as "prioritized integrative attending", which involves giving their own playing a high priority and others' playing a lower priority while processing the relationship between parts (Keller, 2008).

Prioritized integrative attending is cognitively demanding because it requires continuous, simultaneous segregation and integration of information from different sources. It is likely reserved for situations where a musician has specific expressive goals in mind. Outside of these situations, performers may use selective attention or "nonprioritized" integrative attention. Selective attention involves focusing on a particular part of the ensemble texture to

the exclusion of all others, while nonprioritized integrative attention involves focusing on the aggregate structure instead of any individual part.

Musicians' use of effortful and automatic anticipation and adaptation processes in different musical contexts is influenced by their distribution of attention resources. An ensemble playing well-practiced repertoire may prioritize their own parts, focusing on their own expressivity, and expending little attention on maintaining synchronization. In contrast, improvising ensemble members may prioritize attention towards each other's playing, engaging in effortful anticipation processes if, say, the timing is very irregular.

Visual cues

Instrumentalists' visual cues

Although musicians interact with each other and their audiences primarily through sound, there is a substantial visual-motor component to music performance as well. Musicians are in constant motion as they play. Their movements fulfil a range of functions, including sound production, sound facilitation (e.g., adjusting body posture to play with more or less force), and communication with co-performers and the audience (e.g., through gestures, glances, and facial expressions). Non-sound-producing movements are described as "ancillary" (Figure 1).

Ensemble musicians exchange gestural signals to help establish or maintain coordination when they are unable to predict each other's actions using audio signals alone. For example, musicians often exchange gestural cues to synchronize piece entrances or re-entrances following a long pause (Bishop & Goebl, 2015) or to negotiate a sudden tempo change (Kawase, 2014). In the absence of a conductor, a "cueing-in" gesture, which is often accompanied by an exaggerated inhalation, is typically given by one of the performers. Large-magnitude gestures with smooth motion are more effective at communicating the temporal position of the beat than gestures that are small in magnitude or jerky (Bishop & Goebl, 2018a).

Outside of these scenarios, however, deliberate visual communication is not a major contributor to basic ensemble coordination, especially where timing is fairly regular (Bishop & Goebl, 2015; Kawase, 2014). Nevertheless, alignment in periodic body sway, joint uptake in the quantity of motion, and increased physical closeness between musicians may provide visual cues that play an implicit role (Eerola, et al., 2018).

For musicians in small ensembles, coordinated body motion as well as increased eye contact arises as members of an ensemble establish familiarity with each other and the music (Bishop, et al., 2019, Ragert, et al., 2013). Such coordination increases as co-performers work together to construct expressive goals (Chang, et al., 2019). It seems to be an emergent phenomenon, which occurs in real-time as musicians engage in shaping a performance together, in view of each other. When the opportunity to see each other is taken away, gestural coordination declines—showing that it is not simply the result of learned motor sequences.

Conducting

Conductors play a specific role in guiding coordination and expressivity in large ensembles (typically nine or more musicians). During rehearsals, their arm gestures, body postures, and facial expressions communicate to the ensemble how they would like the music to sound; during later performances, their gestures and expressions remind and motivate the ensemble to perform the interpretation that they rehearsed. Conductors' timekeeping gestures help the ensemble coordinate entrances, re-entrances, and tempo changes, and also provide a visual reference for ensemble members who may not be able to hear each other well. A notable attempt at an egalitarian conductorless large orchestra (the "Persymphan") in the early years of the Soviet Union was abandoned partly due to difficulties coordinating tempo changes (Wöllner & Keller, 2017).

Conventionally, conductors' right hand gestures communicate the beat, while their left hand gestures communicate expressive qualities of the music. Conducting style matters, with beat clarity being higher in gestures with smooth motion than in gestures with jerky motion (Wöllner, et al., 2012). Traditionally, conductors have been taught to communicate timing through specific trajectories whose form depends on the meter, and to align beats with moments of direction change. Empirical findings clarify these instructions by showing that the definition of visual beats depends not on the specific spatial location of the hand or baton but on how rapidly it slows when changing direction. Specifically, instrumentalists tend to align their notes with moments of peak deceleration in conductors' gestures, suggesting that beat position is communicated by gesture acceleration, rather than spatial trajectory (Luck & Sloboda, 2008). Instrumentalists' cueing gestures communicate beat position through acceleration as well (Bishop & Goebl, 2018).

While conductors' expressive gestures may incorporate emblems (specific gestures that have a direct verbal translation; e.g., putting one finger to the mouth to say "be quiet"), they mostly form continuous, individualized motion sequences, which are intended to communicate acoustic features such as dynamics, articulation, and tempo changes. Kinematic features of gestures, including movement amplitude, variance, and speed, have been shown to affect the levels of expressivity that musicians perceive. The information that instrumentalists receive from a conductor can vary, depending on where in the orchestra they are seated. Musicians seated directly in front or to the left of the conductor gave higher ratings on scales such as perceived arousal and expressive communication than did musicians seated to the right of the conductor (Wöllner & Auhagen, 2008).

Participatory Sense-Making and Creativity

Participatory sense-making offers a perspective on how participants in a collaborative activity like music-making construct meaningful experiences through real-time interaction with each other (van der Schyff, et al., 2018). This perspective is situated in a theoretical framework that conceptualizes cognition as embodied and enactive. The embodied dimension of this framework emphasizes body involvement in cognitive processes. The enactive dimension emphasizes the dynamic relationship between people and their environments. By this account, ensemble musicians play an active role in constructing a sonic environment as they play, rather than responding passively to notes in the score or co-performers' sounds.

"Sense-making" describes the process through which a person constructs meaning out of their interactions with the environment (De Jaegher & Di Paolo, 2007). Sense-making is "participatory" when it occurs in a social context, causing individual sense-making to be influenced by social dynamics. According to this perspective, the musical product of a group

performance is not a fixed or predetermined structure, but rather an open structure which continuously shapes and is shaped by the performers in a circular fashion. Because every performance is a result of real-time interaction between musicians and their environment, then every performance is necessarily emergent and unique. Even if the performers have played the piece before—indeed, even if they have rehearsed it extensively—meanings and experiences are constructed afresh in the context of each new performance, although they may be guided by the actions that were practiced in rehearsal.

This approach to conceptualizing ensemble performance has motivated attempts to describe the evolving relationships that emerge between musicians and the music, and show how creativity unfolds across the course of a performance (Bishop, 2018). For example, we might analyze co-performers' rhythmic patterns to see how they construct a call-and-response type dialogue during an improvisation.

Togetherness

So far, we have discussed the mechanisms of ensemble playing, addressing how musicians manage to coordinate their actions and play cohesively while also navigating the array of creative directions that their performance might take. Another dimension to consider is the *experience* of ensemble playing.

Togetherness refers to the enjoyable, intrinsically-rewarding experience of being in social synchrony with others (Keller et al., 2014). This social synchrony can be described as a state of affective-motor resonance, in which both affective (emotional) and motor interactions between group members occur at a pre-reflective level. Togetherness is an emergent phenomenon that may fluctuate throughout a performance as different factors come in and out of play. Therefore, it can be viewed as a spectrum where at one extreme, coordination requires conscious effort and group members feel like individuals performing in parallel, and at the other extreme, coordination is effortless and the group feels as though they perform as a unit.

Togetherness can emerge as an experience shared between performers, between audience members, or between performers and audience members (Moran, 2014). The audience's ability to emotionally engage with a performance and establish shared fluctuations in emotional arousal may support their experiences of togetherness. Audience experiences of togetherness may also relate to whether the audience feels some degree of agency over the performance. In some musical traditions, audiences are encouraged to participate in live performances by moving or vocalizing, often in synchrony with the music. Their participation may be rewarded with a response from the performers or from other audience members. Collective rituals often draw on the feelings of togetherness that emerge as a result of large-scale group participation in musical performances.

Some authors have described togetherness among performers as an aesthetic feeling that emerges in response to musical outcomes combined with the motor activities that led to them (Himberg, et al., 2018). This definition highlights the role of overt motor activity in shaping feelings of togetherness and suggests that proprioception, like audition and vision, could be considered an "aesthetic sense".

Togetherness may be tied to how well performers' skills match the demands of the task. For skilled ensembles, it may depend on whether ensemble members are similar enough in their skill level that they can trust each other to respond to new ideas and maintain the quality of

the collaboration. Members of the Danish String Quartet have described their optimal mode of playing together as involving a "hive-mind" in which individual decisions and explicit predictions of what each other might do are irrelevant (Høffding & Satne, 2019). They talk about having a feeling of knowing "without knowing" what each other will do, which suggests that they are aware of some aspects of their coordination processes but not in conscious control of them. A deliberate attempt to take control of the "hive-mind" can cause it to falter, and the quartet becomes "four students of music playing in parallel lines". Thus, these musicians can *feel* the difference between simple coordination (i.e., playing in parallel lines) and the state of affective-motor resonance that characterizes togetherness.

The experience of togetherness may relate to the degree of self-other integration that occurs during performance. Ensemble playing involves simultaneous integration and separation of information from different sources (see section on Attention). In situations where musicians take up leader and follower roles, they may prioritize self-other separation and attend primarily to either their own playing (in the case of the leader) or the other's playing (in the case of the follower). In situations without designated leader/follower roles, performers may be able to achieve a balance of self-other integration that allows for optimal mutual adaptation (Noy, Levit-Binun, & Golland, 2015). Such a well-balanced state may underlie the experience of togetherness.

Implications for Music Practice

The literature on instrumental ensembles offers insights for practicing musicians and music educators on a range of questions. We focus below on applications that are likely to be of broad interest: identifying ensemble skills that contribute to successful performance, adapting ensemble playing to networked conditions, and developing technologies for musical interaction.

Skill development for successful instrumental ensemble performances

Learning to divide attention, imagine, and listen

The literature highlights a number of cognitive-motor skills that contribute to successful ensemble performance. Central among these are musicians' abilities to anticipate, attend, and adapt to each other's playing in real-time (Figure 1). Student musicians require training and practice to develop these abilities. Therefore, specialized techniques are needed that allow students to practice ensemble skills efficiently in group settings that pose varying coordination challenges. Ideally, these techniques would address the personality characteristics that predispose students towards adopting soloist/leader versus accompanist/follower roles, helping them to develop into players that can move flexibly between roles that require differing degrees of anticipation, adaptation, and prioritized integrative attending (Wöllner & Keller, 2017).

The ability to distribute attention effectively between one's own and co-performers' playing is key to successful ensemble playing, and particularly important if the music requires performers to maintain their own rhythms while resisting the natural tendency to converge to each other's timing. Automaticity in technique is a necessary prerequisite for effective attention control, as redistribution of attention is not possible if it is needed for the performer to maintain basic fluency. For musicians who play notated music that is rehearsed, it can be helpful to establish landmarks throughout the piece that help to guide performers' attention to their own part, their co-performers' parts, or aspects of the combined outcomes (Ginsborg, Chaffin & Nicholson, 2006). In this way, control of attention can be practiced and attentional re-directions can be integrated into the rehearsed performance plan.

Active listening is another skill that developing ensemble musicians should be encouraged to practice. Music teachers who work with student ensembles have described “listening” as a complex skill comprising perception and action components as well as awareness and attention (Schiavio, Küssner, & Williamon, 2020). One teacher gave the example of having students play simple duets to practice hearing “where the music fits in” and having trios follow the full three-part score to integrate the visual and aural components, helping them “bring the piece together”. Other teachers stressed the importance of encouraging students to listen to each other and compare their own playing with others' in order to develop their sense of expressivity.

This knowledge, gained through teachers' practical experience, is supported by empirical findings relating to the role of imagery in ensemble playing. As we discussed earlier, in some performance contexts, it is important for ensemble members to be able to anticipate not just their own playing, but the combined group output. Anticipation informs action preparation, allowing musicians to cater their playing to their expected role in the group output (e.g., attenuate their playing to allow another player's melody to come out). The teachers' comments about active listening also reflect the importance of learning to divide attention between others' playing and your own.

The costs and benefits of familiarity with co-performers

Cohesion in ensemble playing seems to be facilitated when performers are familiar with each other's playing style or have complementary playing styles, although the extent of this facilitation remains unclear. On one hand, the quantifiable effects of co-performer similarity that have been observed on note onset synchronization (Keller, Knoblich, & Repp, 2007) are quickly overcome in the early stages of joint rehearsal (Ragert, Schroeder, & Keller, 2013). Some musicians adopt a more conservative playing style at the start of rehearsal in order to minimize coordination errors (Bishop & Goebl, 2020). On the other hand, interviews with skilled musicians suggest that the benefits of familiarity among ensemble members might affect performance quality at a deeper level, reducing the cognitive effort involved in reading each other's intentions, and allowing for greater trust between musicians and greater automaticity in their interactions. Accordingly, developing musicians should focus on establishing ensemble practicing techniques that allow for a rapid transition from the stage of minimizing errors to the stage of creative collaboration. This may involve using explicit communication with new ensemble members to compensate for the lack of familiarity (e.g., establishing shared landmarks in the music; Ginsborg et al., 2006), and adopting a mindset that prioritizes expressive freedom over simple cohesion so that new members have the opportunity to experience each other's expressive playing styles.

Familiarity between ensemble members may be counter-productive in some musical traditions. In collective free improvisation (CFI), musicians aim to collaborate freely and explore sound structures in real-time, without reference to any pre-determined shared structures or intentions. To avoid inadvertently constructing shared intentions through exposure to each other's playing style, CFI musicians try not to play with the same people on a regular basis. In a study of how CFI musicians ascribe meaning to fragments of improvised music, people who played together often tended to respond similarly, suggesting that they think the same way, or have overlapping “mental models” of improvised music (Canonne & Aucouturier, 2016).

Developing a visual playing style

The literature has also highlighted the importance of developing a visual playing style that is captivating for audiences as well as informative to co-performers. Body motion has a substantial effect on audience evaluations of performed music, influencing perceptions of expressivity and performance quality (Behne & Wöllner, 2011). Viewers are especially sensitive to co-performers' visual interactions. For example, in a study of vocal duet performance, joint attention emerged when one singer looks towards the other, prompting the audience to follow the transfer in gaze (Kawase & Obata, 2016). This finding suggests that visual cues to performers' attention can be used to draw and redirect the audience's attention. Research from the broader joint action literature suggests that interpersonal synchronisation of large-scale motion (e.g., dance movements) signals closeness and formidability to external viewers (Lee, Launay & Stewart, 2020). In the context of orchestral performance, viewers give higher ratings of aesthetic quality when the conductor performs expressively rather than deliberately inexpressively (Morrison, Price, Smedley, & Meals, 2014); conversely, audiences also rate conductors' performances as higher in quality when the orchestra performs expressively rather than inexpressively (Silvey, 2011).

Ensemble musicians are also audiences to each other's playing. As specific gestures can be used to exchange timing cues, developing musicians may benefit from practicing a gesturing style that others can readily follow—that is, by giving large gestures that are carefully timed and clearly demarcate the beat (Bishop & Goebl, 2018). Developing musicians may also consider that a visually expressive playing style which also includes glances towards co-performers could help them present as responsive and engaged in the performance.

Together but apart: Networked performance

Networked music performance, which involves simultaneous collaborative performance by individuals at remote locations, has a long history dating back to the early days of computer networking (Gallagher, 2020). The first networked performances featured electronic music, and as real-time transmission of audio was not yet possible, the performers exchanged data messages in order to influence each other's playing.

Today, the technology exists for transmission of audio and video at a high enough resolution, and with low enough latency, to enable real-time ensemble performance of instrumental music, even in cases where the music requires synchronization between performers. However, few people have access to the highest quality set-ups, so performers must come up with different solutions to cope with persistent issues relating to latency and sound quality. Nevertheless, interest in networked performance is high, especially as it would allow people living in isolated conditions to partake in ensemble music-making and allow music communities to diversity through interaction with people in other locations.

Empirical study of networked performance has sought to identify the challenges involved in performing together via network, understand what these challenges imply about the mechanisms of musical collaboration, and identify solutions or workarounds. The main challenge for most ensembles is latency, which arises as a result of the time necessary to transmit audio signals through the network. Networks with lower bandwidths have higher (and more variable) latencies, which disrupt the automatic error-correction mechanisms that usually enable entrainment and synchronization between performers. This makes maintaining a desired tempo (let alone coordinating fine-grained fluctuations in tempo) very difficult (Bartlette, et al., 2006). Most affected by latency are likely to be ensembles with instruments that produce rapid-onset tones (e.g., percussive instruments like the piano). For instruments

with gradual-onset tones (e.g., bowed strings), the tolerance for inter-instrument asynchrony is higher, and the disruption caused by latency is likely to be less. Likewise ensembles performing music that does not require interperformer synchronization (e.g., music with a turn-taking structure) should be less affected. Common solutions for ensembles struggling with latency are to use a click track, or to record one part (e.g., the percussion) in advance, which the remaining ensemble members can then synchronize with. Some ensembles opt to record parts or voices individually and then combine them in postprocessing (a common technique among virtual choirs).

Of course, as we have discussed throughout this chapter, ensemble playing is not simply a matter of synchronizing complementary musical output. Successful performance involves establishing multi-layered auditory, visual, and motor interactions in a way that allows musicians to collaborate creatively and enjoy a social connection with each other. In a study investigating duos' experience performing while physically separated (connected by video link, and without any latency), musicians reported having to adapt to the unfamiliar situation, which removed some of their usual means of interaction (e.g., breathing), and presented them with different visual cues than normal (Iorwerth & Knox, 2019). They also reported unusual difficulties with tuning and matching each other's loudness levels—a result of playing in separate acoustic spaces and being unable to blend their sounds as they typically would. Overall, the musicians said that they felt less free with their playing than normal and unwilling to experiment; they furthermore questioned whether the setup would work for more complex repertoire. More research is needed to investigate how factors such as individual differences in ensemble skills and familiarity with co-performers affect the quality of networked performances and performers' experiences of togetherness.

One possible path forward for the domain of networked performance would be to shift the focus away from music that was intended to be performed (and often heard) in person—or at least away from the traditional manner of performing this music—and towards musical forms and interpretations that take the so-called limitations of networked playing as central features. This might entail adapting existing works or composing new structures that draw on asynchrony to emphasize the distance between players, or sonify aspects of performer interactions that might otherwise be lost.

Technologies for musical interaction

Recent technological developments have introduced new ways of conceptualizing instrumental ensembles and new methods for musical collaboration. Some of these technologies have applications in music education, and many have the potential to bring collaborative music-making opportunities to a wider range of people.

Expressive accompaniment systems (EAS) comprise one such technology. These are systems designed to act as a duet partner for a human performer. An EAS that is designed to play score-based music must manage four tasks (Bloch & Dannenberg, 1985). First, it must extract musical information from the human performer. Second, the EAS must compare the incoming musical information with the score to determine the performer's position in the score. This comparison must be done continually throughout the performance in order for the EAS to stay aligned with the performer, given that notes might be repeated or skipped or held longer or shorter than the score dictates. Third, the EAS must prepare its own output based on the information obtained from the performer and the score. At this stage, expressive modelling may be used to affect the timing, dynamics, and articulation of the system output. Finally, the EAS must produce its own sound output.

The primary application for EAS is an educational context. Duet playing helps beginning students develop a sense of timing and fluidity in their playing, and allows them to practice distributing their attention between their own playing and the accompaniment. More advanced students might benefit from the opportunity to experiment with different expressive interpretations while preparing for duet performances. While several EAS already exist, equipping these systems with real-time coordination abilities so that they perform in a human-like way has proven challenging. Issues that cause few problems for human co-performers, such as a few missed notes or timing errors, can be highly disruptive to an EAS. As we have discussed (and see Figure 1), coordination between human performers takes place in the broader context of shared knowledge about the musical framework and, usually, shared artistic goals. This shared knowledge shapes the expectations that performers have of each other and how they deal with disruptions.

Ongoing research aims to make EAS more engaging (e.g., by adding a visual component), more responsive (by improving score following and adaptation abilities), and more musically independent (by enabling a wider range of expressive output, which is partially informed by the score and partially informed by the human performer's playing). Indeed, EAS present an interesting medium in which to study the social context of ensemble playing, as features such as responsivity and individuality can be manipulated in a controlled way to determine their influence on musicians' experience and playing quality.

Another category of musical interaction technologies reconceptualize instrumental ensembles by introducing new forms of instrument through which users can interact (Leman, 2008). Such instruments are variable in form, but commonly contain sensors that respond to gestural input such as pressure or motion, or physiological input such as muscle tension. Thus a range of body movements can be used to affect sound in a variety of ways.

A challenge of new instrument development is designing instruments with intuitive gesture-sound mappings (Blaine & Fels, 2003). Traditional acoustic instruments draw on sound-producing gestures that people tend to encounter naturally in the world (e.g., percussive striking or blowing) and allow the performer to affect sound by modifying their gestures in predictable ways. These instruments offer clear affordances that draw on performers' experiences enacting sound in the world (e.g., playing with more force will create louder sound). This means that even in heterogeneous ensembles, musicians playing different instruments readily perceive many of the affordances that are available to each other.

New sensor-based instruments can draw on gestures that are not normally sound-producing, such as sweeping the arm through space or tensing a muscle. On one hand, sonifying these gestures allows people to create music in an individualized and personally meaningful way. Some sensor-based instruments allow for a strongly embodied music-making experience, because they afford gestures that people can readily and naturally map onto certain sound features (e.g., high intensity arm movements result in louder sound). On the other hand, complex gesture-sound mappings may make for a less strongly embodied music-making experience if performers have to concentrate on recalling seemingly arbitrary relationships. Although these mappings may be learned eventually, they can be difficult for performers to internalize and co-performers to follow, impeding their ability to interact and distracting from the social context of the performance.

With new instruments comes the possibility of redefining fundamental aspects of musical collaboration. For example, performers may have the ability to substantially shape each other's sound output through the use of a common interface, resulting in an evolving range of affordances that are attributable to a combination of performers' contributions (note how in Figure 1, sound output helps to shape the musical context of the performance). In contrast to traditional instrumental ensembles, this could lead to a form of collaboration in which participants do not have distinct musical voices or clear agency over any part of the sound output. New instruments that are designed to sonify aspects of human movement (in contrast to traditional instruments, which require fairly specific sound-producing gestures) may lead to forms of collaboration that are primarily motoric rather than centered around sound. This opens the possibility for musical collaborations that exist somewhere between traditional instrumental ensemble performance and dance—where gestural interaction is performers' primary focus and "hearing motion" takes on new meaning.

At present, these newly conceptualized instrumental ensembles tend to engage people who are already involved in music-making activities, including many people with traditional instrumental training. However, some developers have focused on creating technologies that might be accessible to a broader range of users; in particular, those with little or no prior music-making experience or formal musical knowledge. These technologies often engage fundamental entrainment mechanisms, and make use of simple, easy to learn and control body movements. Non-traditional instruments can present users with conditions that encourage a focus on the process of collaboration rather than the product. Musical collaboration might then be approached not with the aim of public presentation, but to experience a social interaction and achieve self-satisfaction through joint musical exploration.

Conclusions

In this chapter, we have presented instrumental ensemble playing as a creative process, in which ensemble members establish a resonance that allows them to perform as a single unit. A combination of individual and group-level functions are needed for the ensemble to maintain expressive flexibility and adapt to disruptions. We have also emphasized the social context of ensemble playing, and the importance of togetherness as a source of motivation for interaction at both social and musical levels. To conclude, we want to highlight that although all forms of instrumental ensemble playing have some points in common—notably, the need to establish group dynamics that allow for flexibility, and the involvement of basic sensory-motor and cognitive processes such as anticipation, adaptation, and attention regulation—ensembles differ widely in their performance goals and how they approach them. As we see in the developing domains of networked performance and musical interaction technology, the concept of musical collaboration is continually evolving.

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Reflective Questions

1. Music ensembles across genres value creativity and spontaneity. But how spontaneous are they really when playing music that they have previously practiced? How would you assess this?
2. Across different musical contexts, what roles do planned and emergent coordination play? Does the degree of co-performer familiarity and musical experience affect these roles?
3. How would you test the effectiveness of different ensemble practicing techniques? What criteria could be used to define success, and how might these vary across genres?
4. Interviews are a useful way of studying musicians' performance experiences, but they have some limitations. Musicians may struggle to put into words what they experience and remember exactly what they thought and felt during an earlier performance. What are some other ways to evaluate musicians' experiences of playing music together?
5. How might you use new musical interaction technologies to allow collaboration between instrumentalists and listeners? How might such collaboration affect the experiences of everyone involved?

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