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MUSICAL ENSEMBLE SYNCHRONISATION

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ABSTRACT

Ensemble musicians coordinate their actions with remarkable precision. The ensemble cohesion that results is predicated upon group members sharing a common goal; a unified concept of the ideal sound. The current paper reviews research on three cognitive processes that enable ensemble musicians to realise such shared goals. The first process is auditory imagery; specifically, anticipating one's own sounds and the sounds produced by other performers. The second process, prioritised integrative attention, involves dividing attention between one's own actions (high priority) and those of others (lower priority) while monitoring the overall, integrated ensemble sound. The third process relates to adaptive timing, i.e., adjusting the timing of one's movements in order to maintain synchrony in the face of tempo changes and other, often unpredictable, events. It is assumed that ensemble cohesion is determined by the interaction of these processes.

1. INTRODUCTION

Ensemble musicians are able to synchronise with remarkable precision and flexibility (Rasch, 1988; Schögler, 1999-2000; Shaffer, 1984). Consider a pair of pianists playing a duet. How do they coordinate their actions so as to produce complex sound patterns that—far from being mechanically regular—are exquisitely structured in time? The ability to synchronise in this way obviously relies on considerations apart from the technical command of one's instrument. To produce a cohesive ensemble sound, the pianists must hold a common goal; a shared representation of the ideal sound.

This paper begins by discussing ensemble cohesion and shared musical goals, and then goes on to describe research addressing three specific ensemble skills that are assumed to enable performers to realise such goals. These core ensemble skills, which are rooted in cognitive processes that most likely facilitate interpersonal coordination more generally (see Sebanz et al., 2006), are anticipatory auditory imagery, prioritised integrative attention (a form of divided attention), and adaptive timing.

2. ENSEMBLE COHESION & SHARED GOALS

Ensemble musicians usually aim to interact in a manner that is conducive to producing a coherent musical entity. The term 'ensemble cohesion' refers to how well separate instrumental parts gel together to form such an auditory Gestalt. Ensemble cohesion is predicated upon the musicians sharing a common performance goal, that is, a unified conception of the ideal sound.

Performance goals are established while preparing a musical piece for performance through both individual private practice and collaborative rehearsal with other group members (Davidson & King, 2004; Ginsborg et al., 2006; Goodman, 2002; Williamon & Davidson, 2002). These goals then reside in memory as idealised mental representations of the sounds constituting the musical piece (Palmer, 1997; Rideout, 1992). Thus, performance goals embody a performer's intentions and expectations about how his or her own sound and the overall ensemble sound should be shaped dynamically over time. With such goals in mind, musicians develop performance plans that guide the motor processes involved in translating the goal representations into appropriate body movements (Chaffin et al., 2002; Gabrielsson, 1999).

It seems reasonable to assume that ensemble cohesion should be high to the extent that performance goals related to the overall sound are matched across ensemble members. However, shared goal representations do not, in and of themselves, ensure ensemble cohesion. Performance goals must be realised (via the execution of performance plans) under the real-time demands of live musical interaction. Three ensemble skills that are purported to enable performers to accomplish this—anticipatory auditory imagery, prioritized integrative attention, and adaptive timing—are considered next in turn.

3. ANTICIPATORY AUDITORY IMAGERY

Ensemble cohesion requires each performer to anticipate his or her sounds and the sounds produced by other performers (to varying degrees). These forms of anticipation, or expectancy, involve auditory imagery.

With regard to anticipating one's own sounds, musical intuition dictates that greater performance excellence can be attained by imagining the ideal sound than by concentrating on motor technique (e.g., Trusheim, 1993). This notion sits comfortably with the ideo-motor approach to voluntary action. The central tenet of the ideo-motor approach is that actions are triggered automatically by the anticipation of their distal effects (James, 1890; Prinz, 1987). As James (1890, p. 774) pointed out, a singer needs to think "only of the perfect sound" in order to produce it.

Anticipatory auditory imagery may facilitate performance in a number of ways. First, such images may prime appropriate movements via functional links between auditory and motor brain regions that have developed through experience playing a musical instrument (see Bangert et al., 2006; Lotze et al., 2003). Second, auditory imagery may assist performers in meeting precise temporal goals, such as a steady tempo, by stabilising motor control processes (Keller & Koch, 2006; Keller & Repp, 2007).

Finally, anticipatory auditory imagery may facilitate rapid performance by enabling thorough action preplanning. Interestingly, the degree to which performers engage in anticipatory auditory imagery during such planning increases with increasing musical experience (Keller & Koch, in press). Thus, although James' singer needed only to think of the ideal sound in order to produce it, he probably required a considerable amount of practice before being able to conjure such thoughts accurately and reliably. It is quite likely that all this time spent honing his ideo-motor chops brought loneliness, and may have eventually prompted James' singer to join a choir.

In order for James' singer to coordinate with his fellow choristers, it would have been necessary for him to predict what they will do, and, even more crucially, exactly when and how they will do it. Musicians may make such predictions by using auditory imagery to simulate the upcoming productions of their co-performers. This process was investigated recently in a study of piano duet performance (Keller et al., 2007). Expert pianists were required to record one part from several unfamiliar piano duets, and then to play the complementary part in time with either their own or others' recordings after a delay of several months. It was assumed that pianists would be able to simulate upcoming events best in their own recordings because in this case the simulation is being carried out by the same cognitive/motor system—with all its idiosyncratic constraints—that generated the events in the first place. This was indeed the case: Pianists were more accurate at synchronising with their own recordings than with others' recordings.

4. PRIORITISED INTEGRATIVE ATTENTION

There is usually a lot to contend with during ensemble performance. Individual musicians are not only responsible for producing their own parts correctly, but they must also maintain awareness of the relationship between their parts and parts played by others. It has been argued that prioritised integrative attention is the optimal strategy to meet such multiple-task demands (Keller, 1999, 2001). Prioritised integrative attending involves dividing attention between one's own actions (high priority) and those of others (lower priority) while monitoring the overall ensemble sound. It is assumed that this attentional strategy facilitates ensemble cohesion by allowing musicians to adjust their performances based on the online comparison of mental representations of the ideal sound (i.e., the performance goal) and incoming perceptual information about the actual sound.

A confluence of Mari Riess Jones' dynamic attending theory (Jones & Boltz, 1989; Large & Jones, 1999) and Daniel Kahneman's (1973) claims about fluctuations in autonomic arousal has led to the proposal that metric frameworks may be a mechanism that drives prioritised integrative attending during ensemble performance and listening (Keller, 2001). Metric frameworks are cognitive/motor schemas that comprise hierarchically arranged levels of pulsation, with pulses at the "beat level" nested within those at the "bar level" in simple integer ratios such as 2:1 (duple meter), 3:1 (triple), or 4:1 (quadruple) (see London, 2004; Palmer & Pfordresher, 2003).

Metric frameworks may facilitate rhythmic perception and action by encouraging listeners and performers to allocate their attentional resources in accordance with periodicities underlying the music's temporal structure. In the case of ensemble performance, metric frameworks may modulate the amount of attention that is *available* at a particular point in time (via arousal mechanisms) and the amount of attention that is *actually invested* at this time (via dynamic attending processes) in a manner that is conducive to the flexibility required to integrate information from different sources while tending to a high priority part (Keller, 2001). Metric resource allocation schemes could thus promote ensemble cohesion by allowing performers to use a common attentional template to accommodate the different surface details of their individual parts.

Support for the hypothesis that metric frameworks play a role in prioritised integrative attention comes from studies designed to capture the cognitive and motor demands of ensemble performance using perception- and production-based behavioural tasks (Keller & Burnham, 2005). In a listening task, musicians were required to memorise a target (high priority) part and the overall aggregate structure (resulting from the combination of parts) of short percussion duets simultaneously. Recognition memory for both aspects of each duet was found to be influenced by how well the target part and the aggregate structure could be accommodated within the same metric framework. Analogous results were obtained in a "rhythmic canon" study that required percussionists to produce memorised rhythm patterns while listening to different patterns, which also had to be subsequently reproduced.

5. ADAPTIVE TIMING

The most fundamental requirement of ensemble performance is the temporal coordination of one's own movements and sounds with those of others. To satisfy this requirement, musicians must constantly adjust the timing of their movements in order to maintain synchrony in the face of tempo changes and other, often unpredictable, events. The mechanisms underlying such adaptive timing are usually investigated with paradigms that require finger tapping in time with computer-controlled pacing sequences (for reviews, see Repp, 2005, 2006). An overarching assumption in this work is that the human brain is capable of instantiating timekeepers (interval generators or oscillatory processes) that can be used to control the temporal aspects of perception and action.

Ensemble performance requires timekeepers in separate individuals to be synchronised, or coupled, with one another. Such synchronisation is achieved via error correction processes that adjust each individual's timekeeper based on asynchronies between the timing of their actions. Specifically, adaptive timing is subserved by two independent error correction processes: *Period correction*, which refers to an adjustment of the timekeeper interval or oscillator period, and *phase correction*, which refers to an adjustment to the way in which the sequence of pulses generated by one timekeeper is aligned against the

sequence of pulses generated by another timekeeper (Mates, 1994). Phase correction is required constantly (because asynchronies are inevitable), while period correction is needed only when there is an obvious change in tempo. Research on these processes has yielded findings suggesting that phase correction takes place automatically, whereas period correction requires conscious awareness and attention (Repp, 2001; Repp & Keller, 2004), and that phase and period correction have distinct neural substrates (Praamstra et al., 2003; Stephan et al., 2002). Promising theoretical models of error correction have been developed (see Pressing, 1999; Vorberg & Wing, 1996).

Ensemble cohesion may vary as a function of the sensitivity of ensemble members to each other's use of error correction. The results of a recent study suggest that each individual from a pair compensates for timing errors produced by their partner, as well as their own errors, when tapping alternately in time with an external beat sequence (Nowicki et al., 2007). Such mutual error correction could serve to make multiple ensemble performers sound as one.

In another recent study (Repp & Keller, 2007), individuals were required to synchronise finger taps with auditory sequences presented by a computer that was programmed to implement varying degrees of error correction in a manner that was either cooperative (i.e., aimed at reducing asynchronies) or uncooperative (aimed at increasing asynchronies). Analyses of the humans' behaviour under these conditions suggested that they engaged in fairly constant, moderate amounts of phase correction so long as the computer was cooperative. When the computer was uncooperative, the humans engaged in more vigorous phase correction, which appeared to be supplemented by intermittent period correction in some situations (most notably when the computer did not implement period correction, and therefore was able to maintain its own stable tempo).

To the extent that the above findings generalise to ensemble performance, automatically applied phase correction should be sufficient to maintain synchrony in the face of expressive deviations in local tempo (rubato). However, when it is difficult to anticipate upcoming expressive timing because the stylistic idiosyncrasies of other ensemble members, or the music itself, are unfamiliar, the performer has the option of intentionally increasing the gain of phase correction and/or engaging strategically in intermittent period correction.

Related work has shown that strategic timekeeper adjustments can be used to stabilise challenging modes of perceptual-motor coordination. In a study that required antiphase (off-beat) coordination with an external beat sequence (Keller & Repp, 2005), it was found that musicians were able to counteract the compelling tendency to fall onto the beat by engaging in regular phase resetting based on metric structure (which was induced either by physical accents in the pacing sequence or by the instruction to imagine such accents when they were in fact absent).

6. CONCLUSIONS

The literature review presented in the current paper was compiled under the assumption that musical ensemble synchronisation requires performers to (1) share common goal representations of the ideal sound, and (2) possess a suite of ensemble skills—core cognitive processes relating to anticipatory auditory imagery, prioritised integrative attention, and adaptive timing—that enable these goals to be realised. Additional considerations, including social factors, knowledge of the music, and familiarity with the stylistic tendencies of one's co-performers, may impact upon ensemble cohesion by affecting these three core processes. Finally, anticipatory auditory imagery, prioritised integrative attention, and adaptive timing most likely act together in concert rather than in isolation. The results of an ongoing study addressing how these three ensemble skills interact to determine the quality of ensemble cohesion in piano duos is reported in the presentation for which this paper serves as a synopsis.

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