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Mental imagery in music performance: underlying mechanisms and potential benefits

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This paper examines the role of mental imagery in music performance. Self-reports by musicians, and various other sources of anecdotal evidence, suggest that covert auditory, motor, and/or visual imagery facilitate multiple aspects of music performance. The cognitive and motor mechanisms that underlie such imagery include working memory, action simulation, and internal models. Together these mechanisms support the generation of anticipatory images that enable thorough action planning and movement execution that is characterized by efficiency, temporal precision, and biomechanical economy. In ensemble performance, anticipatory imagery may facilitate interpersonal coordination by enhancing online predictions about others' action timing. Overlap in brain regions subserving auditory imagery and temporal prediction is consistent with this view. It is concluded that individual differences in anticipatory imagery may be a source of variation in expressive performance excellence and the quality of ensemble cohesion. Engaging in effortful musical imagery is therefore justified when artistic perfection is the goal.

Keywords: auditory imagery; music performance; temporal prediction; action simulation; internal models; individual differences

Introduction

Picture a musician striding onto stage and then, after settling into the optimal position, pausing momentarily with eyes closed in silent concentration before producing a sound. This paper addresses the question of whether mental imagery serves some useful function in solo and ensemble music performance, and what that function (or functions) may be. In doing so, we will touch upon topics related to different modes and modalities in which imagery may take place, anecdotal evidence for the use of imagery by performers, putative cognitive and motor mechanisms that underlie such imagery, as well as where these processes may take place in the brain.

Musical imagery is assumed to be a multimodal process by which an individual generates the mental experience of auditory features of musical sounds, and/or visual, proprioceptive, kinesthetic, and tactile properties of music-related movements, that are not (or not yet) necessarily present in the physical world. Such mental images may be generated through either deliberate thought or automatic responses to endogenous and exogenous cues. A large part of the following discussion concentrates on auditory imagery because it appears to be prominent in the phenomenology of performing musicians.

Imagery modes and modalities

Although topics related to musical imagery have occupied researchers for some time,[1–3] little scientific work has dealt specifically with the role of imagery in music performance. This may be due to challenges associated with isolating the effects of auditory imagery on behavior and brain processes in the presence of exogenous auditory stimulation, as well as due to the threat of movement artifacts in recordings of brain activity. It is also possible that the need for performance studies has been partially obviated by the fact that imagining music can itself be considered a form of performance, albeit covert.[4]

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Research on musical imagery has nevertheless been concerned with issues that are pertinent to overt music performance.

A central theme in this work concerns similarities and differences in how structural and temporal properties of sound (e.g., pitch, duration, rhythm, tempo, timbre, and loudness) are represented during auditory imagery and auditory perception.[2] Related research has sought to investigate the degree to which auditory imagery and perception are equivalent in terms of their neural correlates and their effects on behavior.[5,6] A panoply of psychophysical and neuroscientific techniques have been employed to this end, the latter including electroencephalography (EEG),[7,8] magnetoencephalography (MEG),[9,10] functional magnetic resonance imaging (fMRI),[11,12] and positron emission tomography (PET).[13] Evidence gathered with these tools converges on the conclusion that musical imagery involves the interplay of brain regions implicated in auditory and motor processing.[14,15] Exciting new developments have shown, moreover, that it is possible not only to detect whether an individual is engaging in imagery, but also to decode patterns of brain activity associated with the time course of imagining specific musical pieces and rhythmic structures.[16–18]

Another prominent research theme concerns the relationship between auditory imagery and more general brain functions subserving attention, memory, and the prediction of future events.[7,9,19,20] Just as these brain functions differ between people, individual differences—mainly related to musical experience—have been observed in the vividness of auditory images and the potency of their effects on skilled behavior.[21–24] Finally, a growing body of research focuses upon manifestations of auditory imagery in everyday life, both in specialist populations—for example, the musings of music students[25] and the hallucinations that plague schizophrenics[26]—and in regular folk who, for example, experience spontaneous auditory imagery in the form of tunes getting "stuck in the head."[27]

The way in which mental imagery is used by music performers can take several forms.[28] These include mental practice away from the instrument,[29] the silent reading of musical scores (as when conductors and instrumentalists prepare for performance, which requires an advanced skill that is referred to as "notational audiation"),[30] and thinking of the ideal sound during performance.[31,32] Empirical research

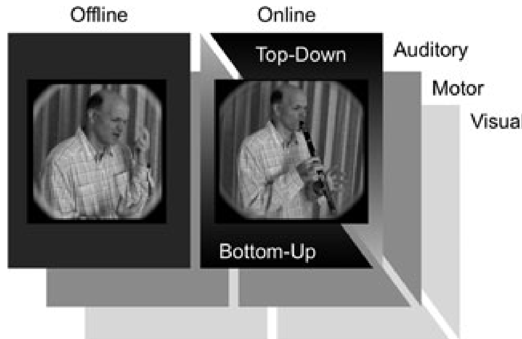

Figure 1. Taxonomy of musical imagery modes (offline, online) and modalities (auditory, motor, visual). The photographs illustrate how, in the offline mode, the performer imagines the ideal sound away from the instrument, while in the online mode, he imagines the ideal sound while playing (in this case with unconventional fingering, thus demonstrating his virtuosity).

has by and large confirmed the effectiveness of these real-world practices. For instance, one study[23] found a positive correlation between pianists' auditory imagery abilities and success at learning novel piano pieces from notation in the absence of auditory feedback.

The previous examples suggest a distinction between the use of mental imagery prior to performance (i.e., offline) and during performance (online). A taxonomy of imagery modes and modalities is shown in Figure 1. Online imagery during performance, furthermore, may proceed via a top–down route—in which the performer deliberately (and possibly effortfully) generates mental images of action goals—and/or a bottom–up route, in which expectancies based on perceptual input automatically trigger mental images. These different modes of imagery may also take place in different modalities—auditory, motor (proprioceptive, kinesthetic, and tactile), and visual—depending on the performer's goals and strategies, as well as the multisensory nature of the context in which the performance takes place (e.g., opera stage vs. isolated recording studio).

Anecdotal evidence for the importance of imagery in musical excellence

Several sources of anecdotal evidence exist that show how covert imagery affects overt musical performance. Some sources are subtle and indirect. For example, Robert Schumann's *Humoreske*, op. 20 for solo piano, contains a third stave sandwiched between the conventional treble and bass staves in one section. A lyrical melodic line is notated on this extra stave, with the mysterious marking *innere Stimme* (inner voice). This inner voice, which apparently represents Schumann's future wife Clara Wieck singing one of her own compositions, is intended to be only imagined.[33] Presumably, doing so affects the character of the parts actually played by the pianist.

There are also numerous more direct anecdotes about the use of mental imagery by virtuoso performers. In one of these, the legendary pianist Artur Rubinstein is sitting on a train with a score for César Franck's Symphonic Variations. Apparently, he learned the entire piece via notational audiation *en route* to the concert.[34]

Less spectacular, but highly informative, accounts of the use of imagery to achieve performance excellence are provided in a study of self-reports by members of the Chicago Symphony brass section.[32] One musician states, "If I don't hear it [the ideal sound] or conceptualize it in my brain, there's no way I'm going to get it" (Ref. 32, p. 146). Another alludes to the use of auditory imagery during private practice for ensemble performance, claiming that "the sound of what is going on in the rest of the orchestra is always in my imagination... You're hearing the whole picture..." (Ref. 32, pp. 145–146). This quote is noteworthy because it implies that imagining the sound of others' parts when practicing one's own part ultimately assists in achieving a cohesive ensemble sound.

Musicians' intuitions about the beneficial effects of imagery on performance are crystallized in self-help books and how-to manuals that address the process of achieving excellence as an instrumentalist.

One influential book in this mold, entitled *The Inner Game of Music*,[35] is remarkable in the sense that it resonates strongly with psychological principles concerning intentional action. For instance, note the correspondence between concepts expressed by bassist Barry Green in this book and William James in his *Principles of Psychology*.[36] The musician states, "When you can hold the sound and pitch of the music clearly in your head... performing it accurately becomes easier. Your body has a sense of its goal" (Ref. 35, p. 75). This echoes James's statement illustrating the operation of his ideo-motor principle (i.e., the notion that actions are triggered automatically by the anticipation of their intended effects): "The marksman ends by thinking only of the exact position of the goal, the singer only of the perfect sound..." (Ref. 36, p. 774). Furthermore, with respect to the benefits of imagery in terms of promoting automaticity in motor control, the musician writes, "Effectively, you are playing a duet between the music in your head and the music you are performing. Any notes you play that don't correspond to your imagined sense of the music stand out, and your nervous system is able to make instant, unconscious adjustments" (Ref. 35, p. 75). The psychologist clearly agrees: "We are then aware of nothing between the conception and the execution. All sorts of neuromuscular processes come between... but we know absolutely nothing of them. We think the act, and it is done" (Ref. 36, p. 790). James' words are fitting to usher us into the realm of cognitive and motor mechanisms that support imagery.

Cognitive/motor mechanisms underlying imagery during performance

Musical imagery relies, in one way or another, on cognitive processes that act upon memory representations. Working memory is involved to the extent that musical imagery requires mental representations of information related to specific rhythmic, pitch, timbral, and/or intensity patterns to be accessed, temporarily maintained, and manipulated in accordance with the demands of the task at hand.[37–39] Two additional mechanisms—which are intimately linked to motor control—are also likely to be relevant to the use of imagery in music performance: action simulation and internal models.

Action simulation occurs when sensorimotor brain processes that resemble those associated with executing an action are engaged in the absence of overt movement.[40–42] Such covert activity may be triggered by observing or imagining an action or its effects,[43,44] for example, tones in the case of music.[45] This triggering is mediated by experience-based associations between sensory and motor processes.[15] Brain activations indicative of musical action simulation are hence especially strong in individuals who have had the opportunity to learn associations between movements involved in playing an instrument and the ensuing auditory effects.[46–49]

Internal models constitute another mechanism that relies on experience-based learning. The idea

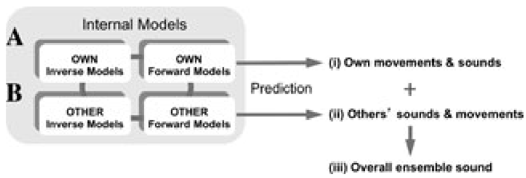

Figure 2. Forward and inverse internal models representing sensorimotor transformations related to (A) one's own actions and (B) others' actions. Together, these models generate predictions that can facilitate (i) anticipatory control of a performer's movements and sounds; (ii) anticipation of coperformers' sounds and movements; and (iii) anticipation and partial control of the overall ensemble sound.

behind these models, put forth by researchers in the field of computational movement neuroscience, is that sensorimotor transformations between bodily states and events in the immediate environment are represented in the brain.[50] There are two types of internal models (see Fig. 2A), both purportedly residing in the cerebellum and communicating with other brain regions.[51] *Forward models* represent the causal relationship between motor commands and sensory experiences related to their effects on the body and environment. *Inverse models* represent transformations from desired action outcomes (sounds, in the case of music) to the motor commands that give rise to these outcomes. Forward and inverse models increase the efficiency of motor control by running slightly ahead of action execution, thereby allowing movement errors to be anticipated and corrected in advance.[52,53] This notion is compatible with so-called "predictive coding" approaches to perception and action,[54,55] which have been applied to musical skills.[56]

Action simulation during music performance entails running internal models that trigger auditory and motor images of one's own upcoming actions.[57] Thus, anticipatory imagery facilitates the planning and execution of musical actions.[58] This type of imagery is a top–down controlled process to the extent that the performance goal—a representation of the ideal sound—is kept active in working memory.

Benefits of anticipatory auditory imagery

A series of studies investigating the role of anticipatory auditory imagery in musical action planning and execution has revealed several potential functional benefits. First, anticipatory auditory imagery assists in selecting which movements to produce,[6] for example, in which sequential order to strike piano keys. Second, such imagery promotes efficient (rapid) movement by enabling thorough action preplanning.[59] Third, it facilitates timing accuracy by optimizing movement kinematics.[60] Finally, anticipatory auditory imagery allows for economical force control by reducing the performer's reliance upon tactile feedback.[61]

The results of other work indicate that the benefits of anticipatory auditory imagery may extend to musical ensemble performance. The temporal precision that characterizes successful ensemble coordination requires performers to predict each others' actions. It has been proposed that these predictions are generated by a second class of "socially endowed" internal models (see Fig. 2B) that serve to simulate coperformers' actions (*cf.* Ref. 62) and to generate predictions about the overall ensemble sound.[57]

In a preliminary investigation of this process, pianists were asked to record one part from several duets and then, months later, to play the complementary part in synchrony with either their own or others' recordings.[63] Synchronization was most precise when pianists played with their own recordings. This finding suggests that the pianists predicted the timing of sounds in the recordings by simulating the performances online, as the match between simulated event timing and actual timing in a complementary part is presumably best when both are products of the same cognitive/motor system. Whether this online action simulation of the other part involved auditory imagery was not addressed.

A subsequent study, however, identified a link between auditory imagery and the quality of interpersonal coordination in musical ensembles.[58] Fourteen pianists were invited to the lab, first in pairs, to perform piano duos while their movements (keystroke timing and anterior–posterior body sway) were recorded, and then individually to perform a task that assessed the vividness of imagery for upcoming sounds in a paradigm that required the production of rhythmic sequences with or without auditory feedback (see Ref. 61). It was found that individual differences in anticipatory auditory imagery were correlated with the degree of synchrony in the duos. Specifically, asynchronies between movements of pianists within duos—at the level of both keystrokes and body sway—decreased with increasing scores on the imagery assessment task. Using imagery to predict the time course of others' actions may seem like an excessively effortful solution to the problem of ensemble coordination, but, as noted earlier, some musicians claim to imagine their coperformers' parts even while practicing their own part in private. If such imagery skills are practiced, then why should they be eschewed during performance?

A series of studies conducted in my lab by Nadine Pecenka has sought to gain a better understanding of the relationship between auditory imagery, temporal prediction, and sensorimotor synchronization. In a first step, separate measures of prediction tendencies and imagery skills were obtained for a large group of individuals (the majority of whom were musically trained).[64,65]

Prediction tendencies were indexed by a task that required finger tapping with auditory pacing signals that contained tempo changes. The degree to which each individual predicted upcoming tempo changes was estimated by computing the cross-correlation between the individual's intertap intervals and the pacing signal's interonset intervals at different lags: The lag-0 cross-correlation is high to the extent that a person is able to predict interonset intervals, while the lag-1 cross-correlation is high to the extent that he or she tracks the tempo changes (see also Refs. 66 and 67). It turns out that people vary widely in their prediction abilities, and that this variation is positively correlated with amount of musical training.

Temporal imagery skills were assessed in the same individuals using a perceptual judgment task. This task required participants to mentally continue a tempo change in a short auditory sequence with a gap, and then to judge whether a probe tone occurred early or late relative to the imagined continuation. It was found that imagery thresholds derived from this task (where low values indicate good performance) were correlated with individuals' prediction scores, and with their accuracy on various sensorimotor synchronization tasks (employing isochronous and tempo-changing pacing signals). Thus, individual differences in auditory imagery ability were related to temporal prediction and sensorimotor synchronization skills.

Next, the ecological validity of the previously mentioned relationship between temporal prediction ability and sensorimotor synchronization skills was tested in an interpersonal coordination task.[68] The same participants were invited back to the lab in pairs, and were asked to tap in synchrony with one another at a moderate, regular tempo. Taps triggered distinctive percussion sounds. A crucial aspect of the experimental design was that the individuals were paired in such a way that they formed three types of dyads: individuals with high prediction tendencies were paired with other high predictors, individuals with low prediction tendencies were paired with other low predictors ("trackers"), and predictors were paired with trackers in mixed dyads. The main result was that interpersonal coordination was most accurate in dyads comprised of predictors.

Neural correlates of imagery-based temporal prediction

The foregoing behavioral evidence is consistent with the notion that sensorimotor synchronization in musical contexts is facilitated by temporal prediction mechanisms that involve auditory imagery. This raises the question of whether there is evidence that these processes are mediated by common brain regions. Previous studies have shown overlap in brain areas involved in imagery and serial prediction for a variety of tasks, including those that require judgments about whether the structure of an ongoing pitch or rhythmic sequence is violated.[69] A meta-analysis has situated this overlap in the (inferior ventral) lateral premotor cortex.[14] Other work has found that real and imagined rhythmic coordination of movement with auditory pacing sequences recruit similar brain regions, including the premotor cortex, supplementary motor area, superior temporal gyrus, basal ganglia, and cerebellum.[70] The relevance of additional cortical and subcortical structures has been highlighted by the results of studies concerned with various forms of auditory imagery, particularly those targeting anticipatory processes[12] and complex sensorimotor transformations,[71] as well as in studies of the role of internal models in temporal prediction.[72]

A recent fMRI experiment aimed to identify the specific brain regions that mediate online temporal prediction during sensorimotor synchronization.[73] The question of interest was whether these regions would overlap with those activated in brain imaging studies of auditory imagery. The behavioral task involved finger tapping in synchrony with tempo-changing pacing signals under three conditions that varied in terms of concurrent working memory demands. In one condition, participants tapped while watching a stream of novel objects; in a more difficult condition, participants counted the number of consecutively repeated objects; and in the most difficult condition, they counted objects repeated after an intervening item. A parametric analysis revealed a network of brain regions in which activity decreased as a function of decrements in the degree of temporal prediction across the three conditions. This network spanned areas that other work has found to be implicated in auditory imagery and auditory attention (e.g., superior/middle temporal gyrus and inferior frontal gyrus), internal models (cerebellum), and processes subserving sensorimotor integration and sensorimotor transformations (sensorimotor cortex). These results provide evidence that auditory imagery and temporal prediction may be linked through brain regions that subserve multiple modalities and levels of processing, and that these links may support anticipatory action control during the synchronization of movements with externally controlled sound sequences.

Conclusions

Mental imagery facilitates multiple aspects of music performance. The deliberate use of anticipatory auditory (and/or motor and visual) imagery during performance may assist in planning and executing one's own actions—with potential beneficial effects on the control of parameters such as timing, intensity, articulation, and intonation—and in predicting others' actions with a view to optimizing ensemble coordination. Individual differences in anticipatory imagery may, therefore, be a source of differences in expressive performance capabilities and in the quality of ensemble cohesion. Although mental imagery during music performance may be effortful, it is justifiable when artistic perfection is the goal.

Conflicts of interest

The author declares no conflicts of interest.

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