Cognitive Processes in Musical Improvisation

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Abstract and Keywords

This chapter discusses the conceptual frameworks in which current empirical studies of cognition in musical improvisation are being undertaken. It takes as its starting point the significant theoretical and empirical contributions of the late Jeff Pressing, musician and researcher, several of which were directed toward opening up this area of investigation. It is on the theoretical bases of models such as his that experimentally accessible hypotheses about improvisation can be constructed. The chapter particularly addresses the issue of transitions and segmentation in improvisation. Comparative and cross-cultural studies of the cognition of improvisation are then briefly reviewed. Finally, the potential of cognitive studies not only to elucidate improvisational processes, but also to contribute to them, is described.

Keywords: cognition, musical improvisation, empirical, Jeff Pressing, improvisational processes, segmentation, transitions

Introduction

IN this article we discuss the conceptual frameworks in which current empirical studies of cognition in musical improvisation are being undertaken. We take as our starting point the significant theoretical and empirical contributions of the late Jeff Pressing, musician and researcher, several of which were directed toward opening up this area of investigation. It is on the theoretical bases of such a model that one can most readily construct experimentally accessible hypotheses about improvisation. We make some cross-cultural and cross-medium comparisons, though briefly; we do not address closely the sociological, philosophical, or educational bases and uses of improvisation, though we have contributed to these areas in previous work (Dean 1989, 1992; Smith and Dean 1997; Dean 2003).

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Models of Improvisation Based on Jeff Pressing's Ideas

Pressing laid the groundwork for a cognitive understanding of musical improvisation. In spite of his focus on cognition, his work is characterized by recognition of the integral and often dominant role of motor function in the performative act of improvisation. This perspective is a natural consequence of his considering the chain of neural processing involved in perceiving and producing sound (e.g., Pressing 1988). These two elements, of perceiving and producing sound, share a special relationship during any musical performance, since the musicians receive feedback from their performance, (p. 40) allowing them to detect errors and correct them by comparison with the intended output. In improvisation, the concept of error is somewhat different from that in the realization of compositions, because any event can potentially be incorporated into an improvisation, and while a sonic event cannot be withdrawn, it can be subject to retrospective "erasure," reinterpretation, or repositioning (Smith and Dean 1997). While motoric function is normally central to musical improvisation, even in this idiom it may be somewhat evaded, as in the case of the computer-interactive improviser. More generally, improvisation in some spheres, such as dance, involves an intensive reliance on motor function, whereas in others, such as text generation and performance, this reliance can be more distant.

In musical improvisation, perceptual feedback also shapes the improviser's decisions as to the course that the music will take. Influenced by "closed-loop" theories of motor learning, Pressing describes the establishment of "perceptual traces," which are representations of intended movements established by practice. These perceptual traces come to form the basis of comparison between intended and realized performance (Pressing 1988). With increasing experience, Pressing argues, improvising musicians refine their perceptual abilities as well as their perceptual traces and error correction, such that performance is nuanced, flexible, and largely automatized. For Pressing, improvisational control is heterarchical more than hierarchical, characterized by redundancy and consequent flexibility, and by a feeling of "going with flow" more than a "top-down" conscious monitoring of decisions. The concept of "flow" has been elaborated by Csíkszentmihályi (1996) and championed in relation to free jazz by Mazzola (Mazzola and Cherlin 2009). Thus the flow of microstructural events can generate macrostructure in the resultant musical stream. That is not to say that there is no role for conscious attention in improvisation. "Tonal imagery" may also play a part, acting as the perception of internal images of either reproduced (recalled) or produced (created) material, at the same time as perception of the actual sensory environment (Pressing 1988). Pressing clearly did not intend the term "tonal" to refer to degrees of tonality, but rather used the term to refer to the structure of tone material.

Improvisation is of special interest for cognitive science since real-time processes place great demands on available resources. In relation to this argument, Pressing (1988) writes that "the need of the improviser is for a good solution, not the best," since the search for an optimum would be too time-consuming and resource-intensive. Reviewing

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physiological and neurological literature, Pressing concludes that improvisers have the biological capacity to react to unexpected changes, and hence to one another's new ideas, about twice a second. This feature of improvisation is of course one of the aspects that contributes to its potential for unique outputs and unique interactions between musicians.

Pressing outlined a model of improvisation with aims to explain how people improvise, how they learn to improvise, and to explain the genesis of novel behavior (Pressing 1988). The model is simple in its starting point as a sequence of non-overlapping sections. Each section comprises musical events and is called an event cluster. Each new event cluster is generated on the basis of previous events, long-term memory, current (p. 41) goals, and, where applicable, a referent. The model allows for variations in cognitive strength associated with different "objects" (cognitive units or entities such as a chord or gesture), reflecting attentional loading, which is tantamount to the object's importance within the improviser's internal representation. In producing a new event cluster, Pressing proposes two types of continuation, namely "associative" and "interrupt" generation. In associative generation, continuity is sought between event clusters with objects high in cognitive strength assuming a continued importance, while interrupt generation represents a break with previous events.

Objects, which can in some ways be conceptualized as musical content, are not the most crucial elements of Pressing's model. Rather, what he terms "features" and "processes" allow for control of the improvisation. Features are the common parameters of multiple objects. Processes describe changes in objects or features over time. Features and processes together form dynamic patterns, and these are at the core of improvisational cognition. In the modest development of this theoretical stance to which the first author contributed (Dean 1989, 1992; Smith and Dean 1997; Dean 2003), the role of ongoing process is emphasized and generalized to the other arts beside music. The process may be such as to generate the objects rather than simply acting on them. In addition, the distinction between process and object readily permits the conception that event-clusters might be non-overlapping in some situations but overlapping in others, particularly by means of continuity of a single process, while the features differ between segments, or by continuity of an object set while the process differs.

The concept of process readily accommodates the situation in which improvisers play together: they may each bring different processes to bear on shared objects, or vice versa, hence generating a diversity of features. A related issue put forward in our earlier work (Dean 1989, 1992; Smith and Dean 1997; Dean 2003) is the possibility that within certain limits improvisers may choose whether or not to adopt what we then described as a "sensory" stance, that is, one in which they respond to ongoing streams besides their own. Somewhat as John Cage encouraged us to perceive environmental sounds outside the control of a performer as part of the musical process, improviser A may construe the musical stream of co-improviser B either as mutable, susceptible to influence from A, or vice versa. And similarly, A may consciously or unconsciously adopt an exogenous (which is a more appropriate term in the context of cognitive studies than our previous "sensory") or

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endogenous (previously “non-sensory”) orientation in relation to whether to respond to B’s stream. Extreme cases of such endogenously oriented interactions occur during improvisations in which the participants do not hear each other (for example, sometimes in trans-internet improvisation), or in which one participant is a computer agent that does not “hear” the input of its partner(s). The work of the Hub, our co-editor George Lewis, and many others, including the first author, have exploited such possibilities of computer-interactive improvisation, and mostly emphasized the capacity of computer-agents not only to generate autonomously, but also to process and exploit incoming musical streams from their partners. Large-scale evolutionary processes in musical generation may also occur with such computer-agents (c.f. McCormack et al. 2009).

(p. 42) Overall, Pressing’s model, together with an enhanced emphasis on process as a separable element, and on interaction as an additional dimension, may be thought of as an Interactive Object/Feature/Process (IOFP) model. This appropriately brings to mind many of the core concepts of the cognitive processes in creativity in general, such as those in Finke’s GENEPLORE model. Here, repeated cycles of generation (of *objects* in our terminology), followed by exploration (giving rise to detectable features as a result of ongoing process), and then by a refinement or selection step, take place. We have proposed a similar model for the long-term processes of research-led practice in the creative arts (Smith and Dean 2009). But even in a short-term improvisation, the aspect of refinement and selectivity can occur, both when a solo improviser chooses which objects, features, or processes to continue and which to discontinue, and when a group improviser selects, among all the available objects, features and processes present or preceding in the performance. It is the selection step that is central to biological or social evolution in the large time frame, and to the iterative cycle of research-led practice we have identified. And while selectivity in evolutionary biology operates largely on the basis of fitness (for survival and reproduction), it may operate on any basis in a creative or socio-cultural system. In the case of socio-cultural systems this brings attendant ethical risks, since many of the selective bases might not produce outcomes that are beneficial for all or a majority of people. This is not to say that creative work is ethically free of risk, but rather that the appropriate and potentially valuable range of selective approaches is exceedingly broad, since they are not bound by purely functional considerations.

Some Implications of the IOFP Model for Cognitive Research

In this brief section we illustrate the kinds of experimental questions that can be raised on the basis of the simple model just described. These illustrations are meant to be suggestive rather than exhaustive. Commonly, the ideas one can develop prove difficult to investigate directly, because of the complexity of human cognition and the moderate development of the research field, as well as the complexity implied by an interactive model. So it is necessary first to investigate what often seem like the most simplistic questions. To those outside experimental science these reductive experiments and their conclusions

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may seem obvious, predictable, and even intrinsic, but they nevertheless form a necessary step in the long-term project to understand the cognition of improvisation. In what follows we mix examples of the inaccessible and complex with the reductively simple, again, for our suggestive purposes.

The possible primacy of the motoric considerations emphasized by Pressing leads to the suggestion that improvisation is largely unconscious, since it necessitates the learning of basic structures and movements. Can one readily distinguish a conscious from an unconscious process experimentally? Sometimes in cognitive science such a (p. 43) question is reinterpreted as one that asks: is attention required for the task at hand, or not? As Pressing argued, it may be necessary to learn to minimize the attention required for many motor actions (musical or during walking, etc.) such that the organism has enough attention available for other impinging perceptual streams. A reciprocal possibility when improvising on an instrument is that it is the motoric demands that drive the production of the musical objects, features or processes. The experience of David Sudnow in learning slowly to improvise at the piano (Sudnow 1978) could be seen partly in this light, and most improvisers would also recognize the influence of the physical structure of their instrument, and the process of playing it, on the range of musical outputs they generate. To take an extreme example, playing chordally is much more obvious for a pianist than a trombonist, yet both can ultimately achieve this if they wish, the trombonist through the use of a variety of techniques for multiphonic generation of sounds.

Returning to attention, a common empirical approach to the question of how much attention is applied to some particular activity is to enquire whether the precision and speed with which another task is undertaken is reduced when it is done at the same time as the specified activity (say, improvising a flurry of notes). It is probably obvious that this is not an easy experiment to achieve. For example, if attentional resources are in abundance in relation to demand, there will be no interaction. And if attentional resources are modality-specific (for example, hearing calls upon distinct resources from vision), then again there can be no interference between cross-modal tasks. Even when it can be demonstrated that performance on one task is decreased by the simultaneous demands of another, this is clearly a quite indirect assessment of attentional demands and even less directly related to the issue of conscious versus unconscious behaviors. The field of attention is huge and developing (Pashler 1998; Pashler and Johnston 1998; Knudsen 2007), but there are indications that musical activity can focus it. For example, Jones and colleagues have demonstrated that if participants are familiarized with a metrical rhythmic pattern, they develop an expectation of the sonic event that occurs on the emphasized beat of the pattern, and at that point in time they also show greater acuity in detecting certain sonic features of the sound than when the sound is heard at an unexpected (non-metrical) time (Jones and McAuley 2005; Jones 1992). On the other hand, there is evidence for pre-attentive processing of auditory timing and intensity changes (e.g., Repp 2005; Tervaniemi et al. 2006).

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Returning to the IOFP model, one might readily envisage that increased attention would occur at moments of associative or interrupt generation (i.e., at section boundaries). In our own studies, we have reinterpreted this idea as suggesting that there should be changed skin conductance at such points, since skin conductance is a physiological response reflective of psychological arousal (which is commonly related to increased attention), and it is a response that is seemingly not open to our conscious control. The response is part of what is therefore termed the autonomic nervous system, because of its resistance to conscious control. Unlike many neuroimaging techniques, such as magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI), skin conductance can be measured under fairly normal keyboard performing conditions. (p. 44) This line of discussion suggests that ultimately such studies of the roles of attention in improvisation will be meaningful, but there is a very long way to go as yet to translate the observations of neurophysiology and neuroimaging into clear-cut interpretations specific to this framework.

When we consider the psychology of interactions between co-improvisers, clearly the difficulties just discussed are magnified hugely, but there are also new questions. For example, are there leadership functions expressed across the “interruptions” when musicians are improvising in an exogenously oriented manner? Some experimental hypotheses can be made as the first step toward addressing such a complex issue. For example, if changes in skin conductance (or some other neurophysiological response) distinguish interruptions from the surrounding periods in the work of a solo improviser, then one would expect a distinction in the nature or degree of these changes between different co-improvisers. Similarly, someone leading an interruption should show a characteristic skin conductance change signature in advance of a co-improviser. The co-improviser would show different responses thereafter according to whether or not he chooses to cooperate and cohere with the form of the interruption (e.g., takes up a newly introduced process). Such hypotheses become accessible providing one has the musicological tools and hypotheses to distinguish the postulated leaderly interruption from a follower’s behavior and to distinguish cooperation from a decision to ignore the instigated idea. Such distinctions can be made by computational analysis of musical and acoustic features, providing one can distinguish among the musical contributions of different participants. We mention later some simple experiments in which such musicological analyses are facilitated in some cases by providing clear-cut referents for improvisers to use, requiring particular types of interruption: for example, requiring transition from soft to loud or from sparse to dense playing. We complement these referents with free improvisations to allow totally realistic conditions also.

A Brief Survey of Empirical Studies on Cognition in Musical Improvisation

There have been numerous empirical studies of the performance of music, but there is a relative paucity of such work on improvised music. Moreover, music psychology is often

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interested in improvisation primarily as a simple departure from score-based music rather than as a sophisticated object in itself. One example can be found in the work of Bengtsson, Csíkszentmihályi, and Ullén (2007). They hoped to uncover the cortical regions associated with simple improvisations by pianists. In one condition, pianists were asked to improvise around a visually displayed melody, while in a subsequent condition they were asked to reproduce their improvisation. A third condition encouraged improvisation without the need to memorize. Improvisation complexity was measured so that it could be aligned with the isolated brain regions active during the condition. (p. 45) Brain activity was measured using fMRI, which images blood flow. One finding was an increase in activity in the dorsolateral prefrontal cortex during improvisation compared to during recall. This brain region is associated with a number of cognitive functions, including "top-down" attending to activity, monitoring working memory (namely the short-term memory necessary for us to relate current perceptions to immediately preceding events), response selection, and the suppression of stereotypical response (Bengtsson, Csíkszentmihályi, and Ullén 2007). All such functions are potentially important in improvisation, and it is perhaps remarkable that such a result was found in the context of such a simple improvisation context. On the other hand, changes in blood flow bear variable relationships to changes in neural activity (Logothetis 2008) and are in any case representative of massive regions of the brain, comprising millions of neurons, commonly coordinated with millions in other regions. Thus the interpretation of such changes is complex, but their occurrence is encouraging.

It stands to reason that Pressing's event clusters and their associative or interruptive generation can be traced by a musicological-statistical analysis of improvised music along the lines mentioned above. Pressing himself was one of the first to attempt a detailed and systematic analysis of the micro-structure of "free" improvisations (Pressing 1987), contrasting with the broader, more macro-structural studies of Jost (1974), Dean (1992), and others. Recording himself performing two short synthesizer improvisations and simultaneously recording the MIDI output, Pressing conducted various computational analyses of both traditional musical features (pitch, rhythm, phrase structure, articulation, dynamics, texture) and what he termed microstructure (essentially expressive properties of music such as rubato, chordal spread, legato-ness). One of his findings was that even his free improvisations seem to comprise organized interval and pitch class structures. A second finding of interest to music cognition was the apparent categorical production of performance dynamics, similar to the phenomenon of categorical perception. In other words, dynamics did not seem to vary continuously; rather, they clustered around certain key velocity means, reminiscent of the perceptual bias to perceive dimensions of sound as discrete categories. It should be noted, though, that when playing with most synthesizers of the time, the relationship between key velocity and apparent loudness was not as satisfactory or nuanced as with an acoustic instrument, which might have accentuated the tendency to clustering that Pressing observed. One of Pressing's two improvisations was suitable as a test of his model of improvisation, and he conducted a partitioning of the music into event clusters and higher-level event cluster classes. The segmenting into

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event clusters was determined on a musical, motoric, and "cognitive" (i.e., based on recorded comments) basis.

In addition to studying free improvisations by retrospectively identifying the objects, features, and processes, one can simplify the situation experimentally by providing referent bases for improvisation. In such improvisations, the musicians improvise around a particular structural or thematic idea, and these ideas may be arbitrarily simple (for empirical studies) or complex. For example, we are studying a series of three section referent-improvisations by professional improvising pianists, in which the referents are simple musical "features." We request an ABA improvisation, over a few minutes, where (p. 46) A might be soft and B loud, but the performance is otherwise unconstrained. An alternative might be sparse-dense-sparse. In an experiment we have a series of improvisation referents, preceded and concluded by a free improvisation (no referent whatsoever). We record MIDI data from a Yamaha Disklavier, an acoustic grand piano with MIDI detection. We record all aspects of the keyboard and pedal performance, together with acoustic and video data, and skin conductance of the performer. After the participants have recorded their improvisations, we ask them to listen back to some of the recordings, and to give a continuous response via a computer interface about their perception of musical "change" (which we leave them to define, and take as an index of their perception of musical structure) and their perception of the expressed arousal and valence (positivity to negativity) of the music. We have conducted extensive studies of such continuous response measures of change and affect during listening tasks undertaken by both non-musicians and musicians (Bailes and Dean 2009, in press; Dean, Bailes, and Schubert 2011).

With this approach, we can use computational analyses informed by the referent instruction to detect whether segmentation (into ABA) is achieved as judged by the musical note stream. Having determined segmentation points, we can also assess whether skin conductance changes were related to this segmentation, thus testing a core implication of the IOFP model. We have developed a range of computational analyses to do with key velocity (relating to loudness produced), pitch and pitch range, tonality versus atonality, rhythmic pulse, and event density. Many of these are based on algorithms developed in the literature previously for use with the performance of composed tonal music. In dealing with the free improvisations we recorded, we apply a multiplicity of these computational analyses, and we are developing a range of approaches that take into account the multivariate nature of our data streams: that is, the performance may use several simultaneous processes acting on several objects to generate the features of any particular part of the improvisation. A combination of quite simple analytical algorithms is surprisingly successful in segmenting even the free improvisations we recorded.

Each of the component processes, objects, and features is potentially a continuously variable stream throughout the performance, from an analytical-computational point of view. We use detailed techniques of Time Series Analysis, a statistical approach that takes account of the "autocorrelation" between successive events in these streams: that is, the fact that if one note is sounded in a high register, the next is more likely to be adjacent than distant; or if a note is sounded loudly, the next is also likely to be loud rather than

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soft. This feature of autocorrelation is very strong in all the music and perceptual responses we have studied, and if it is not considered, statistical analyses and conclusions can be insecure (Dyson and Quinlan 2010). This quite elaborate data gathering approach has generated a few simple conclusions, generally in support of the hypotheses we generated from the IOFP model. For example, improvisers are entirely capable of generating the “interruptions” requested by our referents, and this is readily revealed by our computational analyses of their outputs. More interesting, it does seem that at points of interruption, there generally are changes in skin conductance, and that (p. 47) segments defined by the interruption points are commonly distinct in their skin conductance characteristics.

In the retrospective perception studies, we find that the improvisers identify change in such a way that it coheres with both the referent and the computational analysis. We have yet to complete studies on the perception of affect. We hypothesize that acoustic intensity profiles will be strong predictors of perceived arousal, as we have shown in some depth with composed and improvised electroacoustic and composed piano music previously. Our FEELA hypothesis (see Dean and Bailes 2010), which suggests a Force-Effort-Energy-Loudness-Affect chain, may thus link an improviser with listeners and with other improvisers. This role for energy and loudness, corresponding to the physical property of acoustic intensity and its perceptual counterpart loudness, would be consistent with the suggestions of categorical velocity generation made by Pressing. The role would also cohere with our other observations that statistical patterns of intensity in electroacoustic music (both composed and improvised, see Dean and Bailes 2010) and in a wide range of improvised music (Dean and Bailes 2010) share recurrent patterns of intensity in which crescendi are shorter and show faster dynamic change than diminuendi. This can readily be interpreted as a device, perhaps originating from statistical learning of environmental sounds, by which musicians are able to modulate attention on the part of the listener and sometimes of their fellow performers. In agreement with these suggestions that intensity and timing/rhythm are of particular importance in the perception of improvisation, Keller, Weber, and Engel (2011) indeed report that a majority of participants in a study in which the task was to listen to performances and try to distinguish which were improvised and which were imitated indicated that they used information about timing/rhythm (16/22 listeners) and intensity (12/22). These parameters also correlated with activity in the left amygdala, an area of the brain with which many functions, including fear and aversion, have been associated. It is difficult to interpret this functionally, but the existence of anatomic specificity in the response supports the idea that it is distinctive.

In ongoing work we will also be assessing the capacity of the various object, feature, and process streams, discussed earlier, to predict the affect that listeners of the music perceive, based on our computational analysis of the performances. In other work (Gingras et al., unpublished), we have indeed found that expressive performance features (in a baroque harpsichord fantasia by Louis Couperin), such as event timing, can be predicted by the information and entropy flow of the composition, using the Information Dynamics of Music (IDyoM) model of Pearce and Wiggins in collaboration with them. In the near future our improvisation studies will assess whether there are separable contributions of

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the object/feature/process streams that relate to pitch, timbre, rhythm, and the acoustic intensity profile. From a computational perspective, a feature, as characterized by Pressing, would be an amalgam of several objects that first occur together apposed in time.

These studies of solo improvisers are currently being extended to apply to pairs of keyboard improvisers playing together. Again we record the same complex set of data for each performer as described above, except that they play digital instruments. In this (p. 48) development, we also ask the musicians to alternate in adopting the role of leader in some of the improvised pieces, preceding and succeeding them by improvisations in which the concept of leadership is not mentioned (and not forewarning them that the issue will be raised, since this produces psychological “demand” that may alter their performance).

During the retrospective listening task, after the improvisers have performed, we request some perceptual responses about the music (as above), but also, separately, we ask for an identification of “musical leadership” on a continuous scale and continuously across the pieces. Thus, each player hears the performance back with one player in each headphone ear, is not reminded who is who, and judges which “side” of the audio is musically leading. Again, we do not provide guidance as to what constitutes leadership, leaving that for our musicians to consider in their own terms. Our analyses of this data are in the early stages, but it does seem that interruption is achieved well, and leadership is recognized, both in perceptual retrospection and in skin conductance. There are complex statistical interactions between the various data strands, such that some features of one improviser may be quite predictive of those of another, supporting the idea of there being interactions such as would be expected from a leader-follower relationship, or for that matter, from competitive interactions. We hope to gain much more understanding of these data during the completion of our analyses.

Comparative and Cross-Cultural Issues in Studies of Cognition of Improvisation

Of interest is to ask whether the IOFP model is useful in describing the structure of compositions that have not been improvised. Lehmann and Kopiez (2010) asked whether musical experts could discern when a piece had been improvised rather than composed in a listening experiment. The task was found to be hard, and the authors surmised that the cues listeners used to identify an improvisation had little to do with structure and more to do with its performative character. Studies by Engel and Keller mentioned earlier were consistent with this view, revealing the importance of “instability” in timing and intensity patterns and the possible role of the amygdala. This could have important implications for our understanding of the cognitive processes involved in improvisation. Indeed, Engel and Keller showed that musically experienced listeners had greater facility in making the distinction between improvised and imitated performances, and suggested that this ability “depends upon whether an individual’s action-related experience and perspective taking skills enable faithful internal simulation of the given behaviour.” Keller, Weber, and

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Engel (2011) pursued their study of instability in improvised music by comparing the entropy of keystroke variables in improvisations with imitations of those improvisations. They interpret their finding of greater entropy in keystroke intensity in (p. 49) improvisations as indicative of irregularities in motor control associated with greater uncertainty than occur during the certainty of an imitated performance. While these differences might say more about the impact of rehearsal on performance mannerisms than the relative spontaneity associated with improvisation versus imitation, the approach holds promise for its potential application to compare the entropy associated with different styles of improvisation. For example, it seems likely that the entropy of performance variables would be greater in a free improvisation than in a referent-based improvisation. Keller et al. (2011) measure the entropy of the distribution of keystrokes across an entire piece. A potentially fruitful alternative would be to measure the short-term information content of an unfolding improvisation to explore the time course of uncertainty in both solo and ensemble improvisations, as we have already been doing with the Couperin Fantasia, which is closely related to a long-standing tradition of pre-classical improvisation.

Improvisation can occur in highly defined musical conventions, such as in the performance of baroque music and in the cadenzas of classical concertos, where the song structure is often fixed and recurrent, although it occurs most dominantly in idioms such as jazz and rock. Berkowitz (2010), focusing on classical music, defines improvisation as “spontaneous creativity within constraints” and provides neuroimaging data related to models of improvisation in the classical music context. One can quibble with the somewhat romantic word *spontaneous* given the many hours of training and practice required to achieve proficiency in the required function in classical music as in jazz (Sudnow 1978) or free improvisation. But for the purpose of contrast, composition could be construed in the same terms but as lacking in spontaneity. The cognitive demands placed on improvisers and composers are likely to differ substantially. Recognizing that improvisers both create and perform, Eisenberg and Thompson (2011) examined the effects of competition on their creative production. They found that improvisations were judged to be more creative when improvisers had been told that musical experts would be looking for the “best improvisers.” The link is intriguing, and invites future research into the contextual factors that shape spontaneous creativity.

Jazz has been the focus of empirical study in other work designed to examine the neural activity associated with musical improvisation (Limb and Braun 2008). An fMRI approach was again taken in which professional jazz pianists were required to play on specially adapted keyboards while lying with their head in the MRI scanner. Comparing regions of the brain that were activated during improvisation with those activated during the performance of overlearned material revealed that the improvisations activated brain regions associated with internally generated, stimulus-independent processes, with concomitant deactivation of regions associated with conscious self-regulation. Limb and Braun suggest that “rather than operating in accordance with conscious strategies and expectations, musical improvisation may be associated with behaviors that conform to rules implement-

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ed … outside of conscious awareness" (2008, 4). We have already noted the complexity and difficulty of such a claim; yet it is stimulating and worthy of intensive follow-up.

(p. 50) Others have studied jazz as an essentially social process. For example, Bastien and Hostager (1988) analyzed the performance of a jazz ensemble that had not previously improvised together through the observation of video footage. Focusing on inter-musician communication, they describe the observed importance of shared information and attention. For them, ensemble improvisation is inherently turbulent, and this "produces uncertainty for performers insofar as each musician cannot fully predict the behavior of the other musicians or, for that matter, the behavior of the collectivity" (Bastien and Hostager 1988, 586). Uncertainty requires a focused attention, and this is particularly high at moments of structural change. The authors found that the attention of the musicians was high around moments of potential change in the solo, with dips in between. This attentional focus is consistent with the overarching IOFP model of improvisation outlined above, whereby the structure comprises event clusters that transition by means of either associative or interrupt generation. A further cognitive level is that of the establishment of a shared history of improvisation between the players, during the course of the performance (or more broadly, an improvisation session or stream of sessions). This serves to reduce uncertainty with respect to the behavior of the other musicians and, perhaps, to focus attention efficiently. Bastien and Hostager (1988) argue that the greater the "center of shared information" between musicians, the greater the affordance for increased musical complexity. But many improvisers thrive on the opportunity to play with new musicians, and quite possibly exploit such situations equally toward the generation of complexity and of IOFP components that for them are novel and hardly experienced previously. R. Keith Sawyer has provided frameworks of social psychology for consideration of group interactions, notably in improvisation in both theater and music (Sawyer 2003).

Correspondingly, improvisation is the foundation of many approaches to music therapy (e.g., Nordhoff Robbins), and this may be construed in light of its capacity to encourage both coherent interaction and personalized novelty of expression. The communication and regulation of emotions are important goals, and it is perhaps these goals that prompted Luck et al. (2008) to investigate listener perceptions of the emotion expressed in music therapy improvisations, relating these to their musical content. This musical content tends to be stylistically "free," which is typically less easily described in traditional analytic terms. Luck et al. (2008) summarize the problem as follows: "there is a need to be able to capture the most essential musical features—whatever they are—and connect them to the psychological meanings, especially those relating to emotional content, that they represent. In other words, there is a need to be able to define and extract the clinically relevant combinations of musical features that are 'hiding' within the improvisation" (Luck et al. 2008, 27). The authors were interested in studying the perception of music for which listeners have minimal associations, arguing that this is the case for free improvisation (see our comparable motivation for exploring perceptions of unfamiliar electroacoustic music in Bailes and Dean [2009]), though acknowledging that stylistic associations could always exist for any given listener. A therapist and client jointly improvised at keyboards, with separate MIDI tracks being recorded for each. As in our work,

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listeners (but in this case not the improvisers themselves) (p. 51) rated continuously their perceptions of the emotion they felt was being expressed by the improvisations. A relationship was found between the mean velocity of the key strikes of the music and listener ratings of the activity (arousal) of the music. This is consistent with other reports of a robust relationship between sound intensity and perceptions of loudness with heightened perceptions of arousal (Dean, Bailes, and Schubert 2011), including in improvisation (Dean and Bailes 2010).

We have suggested that in the social context of improvisation, acoustic intensity may be a cross-culturally shared expressive resource (Dean and Bailes 2010), which is consistent with the work of Balkwill and Thompson (1999). In particular, intensity is a powerful predictor of judgments of affect even in cross-cultural studies of Hindustani and Japanese listeners, who come from very different musical cultures. Thus, an improviser might be involved in a real-time collaboration with someone from another culture (say an African-American from the jazz tradition with an Indian classical musician) and yet be able to interact successfully in improvisation. Control of dynamic intensity as a means of projecting an affective profile could be very important here.

Rhythmic structures differ considerably between, say, Western classical music and jazz (mostly symmetric meters), Indian music (quite commonly involving asymmetric meters), and Balkan dance music, with its characteristic aksak ("limping") asymmetric rhythms (such as 3+3+2+3). Yet as can be extrapolated from the discussions by fellow improvising pianists Vijay Iyer on microrhythms (Iyer 2002) and Pressing on "Black Atlantic" rhythm (Pressing 2002), what is shared by improvisers from these different musical and cultural environments is an ability to adapt instantly (or in about half a second) to a rhythmic event and a perception of the relative accentuation of particular events. Accentuation is a combination of acoustic intensity with many features of articulation and timbre (as discussed by Pressing). Thus again, intensity is among the features that may assist musical cross-cultural improvisation, and also perhaps verbal cross-cultural or conflicted discussion through prosody. This may have practical applications in post-dialogic community discussions contributing to social policy development. We have developed this argument in more depth elsewhere (Dean and Bailes 2010).

A cross-cultural study of improvisation was reported by Matare (2009), who was interested in the practice as a manifestation of creativity or musical intelligence among twelve European and twelve African musicians. Musicians from each background were recorded improvising and asked to listen back and provide a commentary on problems, decisions, points of interest, and directions taken. On the whole, the commentaries of the European musicians were focused on aspects of the music itself, such as characteristics of the structure or details of the sound produced, while the African musicians made no explicit mention of music.

There are higher-level issues that relate to cross-cultural cognition in improvisation, such as those adumbrated by George E. Lewis in his contrast between Afro-logic and Euro-logic in improvisation (Lewis 1996). One aspect of his interesting dissection is the idea of

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"telling a story" as central to Afro-logic improvisation, in contrast to more of a structural/ process approach in Euro-logic. This is not to do justice to these ideas (see also discussion in Smith and Dean 1997 and Dean and Bailes 2010), but rather to (p. 52) indicate that both narrative and structural approaches can be readily envisaged as outcomes an IOFP model: both are formed at the interaction of feature and process, and where microstructure meets macrostructure.

Outlook

Cognitive studies of musical improvisation are still at a very early stage of development, but they show great potential. Besides giving insight into improvisational processes, might such studies eventually contribute to them? We would argue they have strong potential to do so. As discussed by Wiggins and colleagues with reference to classical music, a computational approach to the generation of music can use models of cognition as part of the generative mechanism. This may occur by using a statistical corpus of information, as in information content approaches to the prediction of segmentation timing and emphasis in composition and performance (Wiggins, Pearce, and Müllensiefen 2009). More interesting, another computational approach could be to use an ongoing computer analysis of an incoming musical stream in conjunction with a cognitive model of whatever degree of elaboration is available. As mentioned, real-time analysis of input is intrinsic to many computer-interactive improvisation systems that have been developed since the early efforts of the Hub, George Lewis (*Voyager*; Lewis 2000), and Richard Teitelbaum, and large-scale cognitive architecture models (such as ACT-R; Anderson et al. 2004) are also under long-term development. A combination of such real-time analysis, particular generative models, and a cognitive architecture model may suffice to help take computer interactive sound improvisation to another level (see also discussion in Dean 2003; Dean and Bailes 2010). For example, computational "conceptual blending" is an idea of current importance in improvisation with text (see chapters in this handbook by Smith, and by Harrell), and it involves exploiting "domains" of knowledge or of arbitrary codification so as to perform crossovers between them with a flexibility and variability of outcome that is shared by genetic crossovers in organismal evolution. This approach can be applied much more freely with the relatively non-referential components of music than with highly referential words and verbal concepts. Not surprisingly, it has a long tradition of related antecedents in the improvisation systems just mentioned and in commercial software such as the classic program M from the first days of desktop computers in the 1980s. The potential of such approaches (discussed in Dean 2009) has probably only been glimpsed.

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