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Review

The neuroscience of musical improvisation

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ABSTRACT

Researchers have recently begun to examine the neural basis of musical improvisation, one of the most complex forms of creative behavior. The emerging field of improvisation neuroscience has implications not only for the study of artistic expertise, but also for understanding the neural underpinnings of domain-general processes such as motor control and language production. This review synthesizes functional magnetic resonance imaging (fMRI) studies of musical improvisation, including vocal and instrumental improvisation, with samples of jazz pianists, classical musicians, freestyle rap artists, and non-musicians. A network of prefrontal brain regions commonly linked to improvisatory behavior is highlighted, including the pre-supplementary motor area, medial prefrontal cortex, inferior frontal gyrus, dorsolateral prefrontal cortex, and dorsal premotor cortex. Activation of premotor and lateral prefrontal regions suggests that a seemingly unconstrained behavior may actually benefit from motor planning and cognitive control. Yet activation of cortical midline regions points to a role of spontaneous cognition characteristic of the default network. Together, such results may reflect cooperation between large-scale brain networks associated with cognitive control and spontaneous thought. The improvisation literature is integrated with Pressing's theoretical model, and discussed within the broader context of research on the brain basis of creative cognition.

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1. Introduction

Improvisation is one of the most complex forms of creative behavior. The improvising musician faces the unique challenge of managing several simultaneous processes in real-time—generating and evaluating melodic and rhythmic sequences, coordinating performance with other musicians in an ensemble, and executing elaborate fine-motor movements—all with the overall goal of creating esthetically appealing music. Other forms of artistic performance, while similarly demanding, do not require such spontaneous creativity. The question of how musicians improvise is relevant not only to the psychology of music, it also has implications for the psychology of creativity, as understanding the nature of creativity at a high level of skilled performance may shed light on domain-general processes underlying creative cognition. Improvisation research may also inform basic cognitive neuroscience because it provides a unique look at how acquired expertise shapes brain structure and function.

An increasing number of studies are employing neuroimaging methods to explore the brain basis of spontaneous musical composition, using samples of jazz pianists, classical musicians, freestyle rap artists, and non-musicians. Much of this research has focused on understanding the extent to which brain regions associated with executive control mechanisms underlie improvised behavior. Does improvisation rely on the musician's ability to control the creative process, or rather on his or her ability to "let go" of control and allow spontaneous processes to unfold? This review examines the issue of cognitive control in creative thought with the overarching goal of understanding the cognitive and neural underpinnings of musical improvisation.

1.1. Pressing's model of improvisation

Perhaps the most influential model of musical improvisation was developed by Pressing (1988, 1998). Following in the literature on expert performance (Ericsson et al., 1993), Pressing's theory is grounded in the notion that improvisation is an acquired skill that requires a substantial amount of training to achieve expertise. A large body of research in a range of domains suggests that expertise is achieved through deliberate practice, an individually tailored regimen of intensive training typically undertaken with the guidance of an expert instructor (Ericsson et al., 1993). According to the deliberate practice view, eminence in a domain is rarely achieved without thousands of hours of deliberate practice: Ericsson and colleagues have repeatedly demonstrated that experts typically engage in 10,000 h of deliberate practice over the course of ten years before achieving eminence in their field (i.e., the "10-year rule"; Simon and Chase, 1973). Recently, however, researchers have emphasized the role of general cognitive abilities (e.g., working memory capacity; Meinz and Hambrick, 2010) and genetic predispositions (Ericsson, 2013; Tucker and Collins, 2012) in explaining expert performance, thus providing support for the notion that practice is "necessary but not sufficient" for high-level performance (Hambrick et al., 2014; Hambrick and Meinz, 2011).

Domain-specific expertise seems especially relevant to musical improvisation. In addition to the physical and psychological constraints common to other domains of skilled performance, jazz musicians must perform under extraordinary temporal constraints. Improvising requires the simultaneous execution of several processes in real-time, including sensory and perceptual encoding, motor control, performance monitoring, and memory retrieval, among others (Pressing, 1988). Deliberate practice automates some of these processes, freeing attentional resources for other higher-order processes (e.g., generating and evaluating musical ideas). In the absence of such improvisational fluency, the improviser will have difficulty effectively interacting with other members of an ensemble and exerting control over the development of his or her performance.

According to Pressing's model, improvisational expertise involves the interplay between referent processes and a domain-specific knowledge base. Referents consist of cognitive, perceptual, or emotional processes; the knowledge base consists of hierarchical knowledge structures stored in long-term memory (Pressing, 1988). Pressing described referents as a series of well-rehearsed retrieval cues that are deployed during performance, minimizing processing demands and guiding idea generation. Referents interact with procedural and declarative information stored in a domain-specific knowledge base. Through deliberate practice, musicians build a database of generalized motor programs, which can be fluently accessed and executed during performance.

Another component of Pressing's model is perceptual feedback and error correction. These processes allow the improviser to minimize the distance between intended and actual performance (Pressing, 1988, 1998). Pressing distinguishes between short-term (ongoing motor movements) and long-term (decision making and response selection) feedback—both of which are essential for improvisational fluency. In contrast to "open-loop" theories of skilled performance, which consist of a simple input, processing, and output procedure, Pressing advances a "closed loop" model, which extends open-loop models by including feedback integration within the system. Ongoing performance is thus monitored by comparing actual output with intended output, and future performance is adjusted accordingly.

Pressing (1988) conceptualized improvisation as a series of generative and evaluative processes. Although these processes involve some level of cognitive control and conscious monitoring, Pressing emphasized the role of automatized motor processes and routines (e.g., well-rehearsed action sequences). Because of the high demands on information processing and decision-making, Pressing argued that improvisational fluency relies on automatized processes that require minimal conscious attention. The extent to which creative thought relies upon such top-down and bottom-up processes remains a point of debate in the literature on musical improvisation as well as in the literature on domain-general creative cognition (cf. Abraham, 2014; Beaty et al., 2014c; Jung et al., 2013; McMillan et al., 2013; Mok, 2014; Sowden et al., 2014).

1.2. Domain-general creative cognition

The study of musical improvisation provides an opportunity to investigate creativity at a high level of skilled performance. Although improvisation research has traditionally been restricted to the field of musicology, it is also of growing interest to researchers in the field of creativity science. Several literature reviews and meta-analyses on the neuroscience of creativity include studies on musical improvisation (e.g., Dietrich and Kanso, 2010; Gonen-Yaacovi et al., 2013). Moreover, results from behavioral and neurophysiological research suggest that improvisation taps domain-general processes such as divergent thinking (Beaty et al., 2013) and cognitive flexibility (de Manzano and Ullén, 2012b).

The cognitive and neural basis of creative thought has been a topic of increasing empirical interest. Much of this work has employed divergent thinking tasks, the most common of which is the alternate uses task. Such tasks require the generation of novel uses for everyday objects (e.g., a brick), and they are typically scored in terms of fluency (the number of ideas) and originality (the creative quality of ideas). A growing body of evidence suggests that individual differences in divergent thinking reflect a domain-general creative ability: performance on divergent thinking tasks has been shown to predict both past and future creative achievements (Jauk et al., 2014; Plucker, 1999; Torrance, 1988). Moreover, a recent study found that divergent thinking ability in jazz