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Jazz musicians reveal role of expectancy in human creativity

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ABSTRACT

Creativity has been defined as the ability to produce work that is novel, high in quality, and appropriate to an audience. While the nature of the creative process is under debate, many believe that creativity relies on real-time combinations of known neural and cognitive processes. One useful model of creativity comes from musical improvisation, such as in jazz, in which musicians spontaneously create novel sound sequences. Here we use jazz musicians to test the hypothesis that individuals with training in musical improvisation, which entails creative generation of musical ideas, might process expectancy differently. We compare jazz improvisers, non-improvising musicians, and non-musicians in the domain-general task of divergent thinking, as well as the musical task of preference ratings for chord progressions that vary in expectation while EEGs were recorded. Behavioral results showed for the first time that jazz musicians preferred unexpected chord progressions. ERP results showed that unexpected stimuli elicited larger early and mid-latency ERP responses (ERAN and P3b), followed by smaller long-latency responses (Late Positivity Potential) in jazz musicians. The amplitudes of these ERP components were significantly correlated with behavioral measures of fluency and originality on the divergent thinking task. Together, results highlight the role of expectancy in creativity.

1. Introduction

One of the most striking features of the human brain is its ability to be creative. Creativity has been defined as the ability to produce work that is novel, high in quality, and appropriate to an audience (Sternberg, Lubart, Kaufman, & Pretz, 2005). While the nature of the creative process is under debate, many believe that creativity relies on real-time combinations of known mental processes (Goldenberg, Mazursky, & Solomon, 1999), with contributions from the society and culture as well as from the person (Csikszentmihalyi, 1996). However, how these neural and cognitive processes are combined is unknown, as they vary across domains and between individuals.

One model of creativity in real time comes from musical improvisation, such as in jazz music, in which individuals spontaneously create novel auditory-motor sequences that are aesthetically and emotionally rewarding (Bengtsson, Csikszentmihalyi, & Ullen, 2007; Berkowitz & Ansari, 2008; Limb & Braun, 2008; Liu et al., 2012). Jazz improvisers show higher divergent thinking ability and openness to experience, even when compared to musicians with other types of training (Benedek, Borovnjak, Neubauer, & Kruse-Weber, 2014). Longitudinal studies have also shown that improvisation training induces improvements in performance on divergent thinking tasks (Karakelle, 2009; Lewis & Lovatt, 2013). Due to its reliance on domain-general as well as domain-specific processes, the study of improvisation is thought to have implications not only for the study of artistic expertise, but also for the neural underpinnings of domain-general processes such as motor control and language production (Beaty, 2015).

While the mechanisms of creativity are unclear, recent work from theoretical and modeling studies suggests that the processing of deviance, or of unexpected events, is key to creativity (Kleinmintz, Goldstein, Mayseless, Abecasis, & Shamay-Tsoory, 2014; Wiggins & Bhattacharya, 2014). If expectation processing is key to creativity, one would expect that individuals with more training in creativity might process expectancy differently. Here we aim specifically to inspect the role of expectation in creativity, using jazz improvisers as a model.

Across multiple modalities, expectation violations from novel stimuli elicit the P3, a positive ERP as measured using event-related potentials as a peak around 300–600 ms after the onset of target events (Arthur & Starr, 1984; Klein, Coles, & Donchin, 1984; Knight, Scabini, Woods, & Clayworth, 1989; Yamaguchi & Knight, 1991). The P3 is elicited across multiple sensory domains and has generally been linked to engagement, arousal, and novelty detection (Friedman, Cycowicz, & Gaeta, 2001; Murphy, Robertson, Balsters, & O'Connell R, 2011). It includes two subcomponents, P3a and P3b (Polich, 2007). P3a (or Novelty P3) is thought to reflect more stimulus-based attention and novelty detection in the frontal lobe, whereas P3b reflects attention- and memory-dependent neuroinhibitory processes especially in the

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parietal lobe (P3b) (Murphy, Robertson, Balsters, & O'Connell, 2011; Polich, 2007). The P3 can be followed by an additional parietally-centered late positive potential (LPP), around 400–900 ms, which reflects evaluation and affective appraisal, especially for motivating and task-relevant events (Cacioppo, Crites, Berntson, & Coles, 1993; Schupp et al., 2000).

In addition to the P3 and the late positivity, expectation violations for musical harmony, which has been linked to emotion and meaning in music (Meyer, 1956), additionally elicits an Early Right Anterior Negativity (Koelsch, Gunter, Friederici, & Schroger, 2000; Loui, Wu, Wessel, & Knight, 2009; Steinbeis, Koelsch, & Sloboda, 2006). This Early Right Anterior Negativity (ERAN) bears some similarities to the Mismatch Negativity (Naatanen, Simpson, & Loveless, 1982) in that both are sensitive to unexpected acoustic events and may reflect auditory prediction and comparison; however the ERAN is thought to be more specific to the processing of musical syntax and is sensitive to learning and experience (Koelsch, 2009; Loui et al., 2009).

Our general hypothesis is that creativity depends on sensitivity to unexpected events. Specifically, in the domain of music, we expect that jazz improvisers will process unexpected musical stimuli with increased sensitivity and engagement, as indexed by the ERAN and P3, compared to their musician and non-musician counterparts. Furthermore, we expect that neural indices of unexpectedness will be correlated with measures of divergent thinking.

2. Materials and methods

2.1. Subjects

36 subjects (12 female) participated in the study. Subjects were recruited from Wesleyan University and the Hartt School of Music in exchange for compensation or course credit. Jazz improvising musicians, non-improvising (Classical) musicians, and non-musicians were recruited based on their reported musical experience. All three groups ($n = 12$ each, sample size determined from previous studies (Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005; Loui et al., 2009)) were matched in age, general intellectual function as assessed using the Shipley Institute of Living Scale (Shipley, 1940), and short term memory (digit span task). Jazz and Classical musician groups were matched in age of onset and number of years of musical training and pitch discrimination thresholds, but the Jazz group had an average of five years of training in musical improvisation, whereas the Classical group had only non-improvisatory musical training. The Jazz group was identified by two criteria: 1) 5+ years training in music that included improvisation. 2) Active participation in improvisatory musical activities 1+ hour per week. Non-improvising ("Classical") musicians were identified using the following criteria: 1) 5+ years of musical training that did not include improvisation. 2) Active participation in non-improvisatory musical activities 1+ hour per week. Participants were included in the non-musician group if they had less than 5 years of previous musical training. Subjects gave informed consent as approved by the Institutional Review Boards of Wesleyan University and Hartford Hospital.

2.2. Procedures

After subjects gave consent to participate in the study, control tests were done including a psychophysical pitch discrimination threshold-finding test (Loui, Guenther, Mathys, & Schlaug, 2008) to rule out differences due to pitch discrimination, the Shipley test of general intelligence (Shipley, 1940), and a digit span short term memory task (Baddeley, 2003). These showed no significant differences among the three groups as shown in Table 1. Subjects also completed a survey on their musical background, indicating their age of onset and duration of general musical training, the duration of jazz and improvisation training, amount of time spent on musical activities, and their self-rated ability to improvise. The control tests were followed by an EEG experiment (Harmonic Expectation Task) and a behavioral experiment (Torrance Test of Creative Thinking).

2.2.1. EEG: harmonic expectation task

Event-Related Potentials were used to examine musical expectancy in the three groups, borrowing from an established paradigm in music cognition to test for musical expectation (Koelsch et al., 2000; Loui & Wessel, 2007). Stimuli consisted of chord progressions generated from sine wave complexes with fundamental frequencies ranging from 174.61 Hz to 1318.51 Hz. Each sine wave complex was presented with a fixed amplitude envelope with a rise time of 5 ms and a fall time of 105 ms. Sine wave complexes were presented in groups of five, with an inter-onset time of 1000 ms between successive complexes within a group. The fundamental frequencies of the tone complexes formed musical chord progressions that were either of high, medium, or low expectation as predicted by music theory, similar to stimuli used in a previous study (Loui & Wessel, 2007). The high expectancy chord progressions were in accordance with Western music tradition (I-I-IV-V-I). The medium expectancy chord progression replaced the third chord with a slightly unexpected Neapolitan chord, but this chord still functioned correctly according to Western tonal standards (I-I-N-V-I). The low expectancy chord progression replaced the last chord with a Neapolitan chord (I-I-IV-V- N), which is unacceptable in that context within Western tonal standards. High, medium, and low expectation chord progressions were presented with equal probability and played in all 12 keys. Each trial consisted of one such chord progression, followed by a preference rating where subjects were instructed to rate their preference for the chord progression on a scale from 1 (dislike) to 4 (like). Entering a preference rating triggered the next trial, with a new five-chord chord progression. The trials were presented in blocks of 60, and each subject completed at least 3 blocks (maximum 6 blocks) and the keys of all the chord progressions were randomized for each block. In contrast to previous experiments (Loui, Grent-'t-Jong, Torpey, & Woldorff, 2005) which included a different type of deviant to which subjects responded, the present study required subjects to attend to the feature of musical harmony, as these were hypothesized to elicit the ERAN and P3 complex, which were our main ERPs of interest. EEG was recorded using PyCorder software from a 64-channel BrainVision actiCHamp setup with electrodes corresponding to the international 10–20 EEG system. Impedance was kept below 10 kOhms. The recording was continuous with a raw sampling rate of 1000 Hz. EEG recording took place in a sound attenuated, electrically shielded chamber.

2.2.2. Divergent thinking task

A domain-general creativity task was assessed to test whether the Jazz group might be more creative even in non-musical contexts. Subjects completed a short version of the Torrance Test of Creative Thinking (Torrance, 1968), in which they were given six open-ended verbal prompts (e.g. "List all the uses you can think of for a paper clip.") and had three minutes to respond to each prompt. Subjects were told that the task was a measure of general creativity and that they should try to give as many answers as they could.

2.3. Data analysis

2.3.1. EEG: harmonic expectation task

Behavioral ratings were exported from Max/MSP (Zicarelli, 1998) to SPSS for analysis. EEG data were analyzed in BrainVision Analyzer. Preprocessing included applying infinite impulse response filters with a low-pass cutoff of 30 Hz and a high-pass cutoff of 0.5 Hz. Raw data inspection was used to exclude data points with a higher gradient (> 50 uV/msec), high mins and max (> 200 uV), and extreme amplitudes (−200 to 200 uV), resulting in exclusion of 11.8% percent of the segments, with this percentage being similar across groups and across conditions (all $p > 0.10$). Ocular correction ICA was applied to remove eye artifacts for each subject. The data were then segmented into chords