BP Sequencer: A Low-Barrier-to-Entry Assessment Tool for Musical Creativity

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ABSTRACT

This paper introduces a newly designed sequencer of music in the Bohlen-Pierce (BP) scale to assess creative perception and cognition. We begin with a brief overview of scientific studies on musical creativity, leading up to a gap in the field that is unaddressed by traditional studies that compare different forms of musical training and instrument-dependent output for understanding creativity. We then introduce the novel BP sequencer, an experimental interface that affords generating and rating the creativity of novel musical sequences that are uniquely composed in the Bohlen-Pierce scale. We then report three preliminary experiments in which we quantify the number of sequences generated by each individual and isolate the musical-informatic features that were rated as more creative. Participants showed a wide range of creativity in generating novel sequences. Sequences that were rated as more creative were generally longer, had more unique pitches, and had more different interval sizes. Furthermore, a preliminary electrophysiological (EEG) study quantifies three distinct candidate biomarkers for the perception of musical creativity. This novel sequencer of Bohlen-Pierce scale music can provide a useful tool for assessing creative perception and cognition. The code for this tool is freely available, along with video tutorials and documentation.

1. INTRODUCTION

Techniques for the notation, representation, and visualization of music and sound are inextricably linked to the human understanding of musical structure within their broad contexts. These understandings include the cognitive representations that the human mind develops in response to continuous exposure to perceptual input with its statistical regularities in one's environment, that give rise to understanding of musical structure and creative interpretations of said structure in the form of musical outputs. Musical outputs that feature improvisation may, because of their inherently quick-changing nature, require different forms of notation from musical output that are through-composed; this is related to the different forms of mental representation that musicians who practice improvisation may have, relative to musicians who primarily perform through-composed music.

2. STUDIES IN MUSICAL CREATIVITY

Studies in music cognition that compare musicians with different levels of improvisation training have focused on western classical and jazz improvisation genres, mainly due to its relative ease of access to researchers who are conducting neural and cognitive studies of improvisation in lab-based, relatively experimentally controlled environments. In one representative previous study, 38 young adult participants with varying degrees of musical improvisation training completed a novel improvisation continuation task and underwent Magnetic Resonance Imaging (MRI) scans to relate the creativity of musical improvisations to brain structure [1]. In the improvisation continuation task, participants were tested in a lab-based environment with a computer and a MIDI keyboard. The computer presented pre-recorded short musical motifs, and then participants were asked to continue the short motifs on the keyboard and then improvise and extend to the motifs (instructions were to "riff off of" the motifs). Recorded performances were then rated by expert jazz instructors for creativity. Voxel-based morphometric analyses on T1 data showed that creativity ratings were negatively associated with gray matter volume in the right inferior temporal gyrus and bilateral hippocampus. Furthermore the duration of improvisation training, which was significantly correlated with creativity ratings, was negatively associated with gray matter volume in the rolandic operculum. Although experience with a keyboard was positively correlated with creativity ratings, this study notably introduced an improvisation task that could be performed even by participants with no specific musical training. The observation of brain structures that correlate with improvisation experience informs us that the capacity for creativity may be measurable at the level of the brain, and relatable to improvisatory behavior. On the other hand, these anatomical measures are relatively stable over time, changeable only over long periods of practice throughout the lifespan [2]–[4]. More time-sensitive measures of brain activity are needed to observe moment-by-moment fluctuations in the perception and production of creative output. In that regard, another previous study compared the electrical brain potentials (using the electroencephalogram, or EEG) of classical and jazz-trained musicians as they listened to Western chord progressions that were either highly expected (I-IV-V-I), slightly unexpected (I-N6-V-I), or highly unexpected (I-IV-V-N6) [5]. This study found that while jazz-trained musicians, with their well-learned improvisation strategies, were more sensitive to slight harmonic expectancy violations early on in the perceptual pathway (around 100-200 milliseconds after the onset of the unexpected chord), they quickly integrated the unexpected chords into the ongoing musical contexts such that there was less error-related brain activity, as evidenced by a return to baseline in brain potentials by around 800 milliseconds after the unexpected chord onset. In contrast, classical musicians were less sensitive to unexpected chords at 100-200 ms, but showed a persistent significant brain potential difference at 800 ms after the onset of the highly unexpected chord. These results suggest that expectations and contextual information are crucial in the mental representation of musical structure, and that different types of training and enculturation within a musical genre can completely alter the temporal cascade of neural events that give rise to the perception of musical structure.

Using similar techniques of electrical brain potentials coupled with behavioral testing, other studies have shown that differences in mental representation between classical and jazz musicians are localized to the brain mechanisms that generate motor patterns that subserve commonly expected and unexpected chord progressions [6], and are influenced by the cognitive representation of functional categorization on the basis of musical structure as well as on the basis of motoric representations of musical chords and chord progressions [7]. Taken together, this line of research in the neuroscience of music suggests that creativity, as operationally defined by training in improvisation through jazz musical training, involves time-sensitive categorization and reconstruction of functional categories of musical sounds as filtered by the musician's training and experiences. In that sense, studying the effects of training in improvisation is useful for creativity researchers, as improvisation is a form of real-time creativity that can be quantitatively studied [8].

3. CHALLENGES AND MOTIVATIONS BEHIND PRESENT RESEARCH

Although there is much to be learned from these studies, many open questions remain about the nature of creativity that are yet unaccounted for by this line of work. One major limitation lies in the operational definition of creativity as that which is encouraged by jazz training. While common-practice jazz pedagogy often does rely upon improvisation as a core part of the curriculum, this form of training is only available to a select few, and only represents a small part of the broad and diverse musical experiences found around the world. If our goal is to understand creativity through real-time generative musical processes that can reveal some information about our mental representations of musical structures, then studying jazz improvisation only represents a very narrow part of the many possible mental representations.

A more scalable and broadly applicable approach may be to design user-friendly interfaces for musical creativity that rely on minimal training, and can quickly become conducive to studies in the perception and cognition of musical structures as they are being created in real time. To maximize accessibility for use in music cognition studies, and to lower the barrier of entry for individuals with no specific musical training, we make use of novel tuning systems that are different from the world's commonly used musical systems. Specifically, we use the Bohlen-Pierce (BP) scale, a thirteen-tone macrotonal scale that differs from the world's scale structures: while the majority of musical scales around the world rely on octave equivalence [9], with octave being a 2:1 ratio in frequency, the BP scale makes use of the tritave, which is a 3:1 ratio in frequency [10]. Previous innovations in musical notation (presented at TENOR) have considered expansions for non-standard musical systems such as BP, such as by introducing dynamic notation [11]. In the same spirit, here we aim to create a training-independent common ground that affords studies in music perception and cognition, specifically neurocognitive studies of musical creativity, that are relatively independent of musical culture and genre-specific training.

Here we introduce the BP sequencer, a platform-independent tool to assess musical creativity. We describe core features of the user interface and the types of data collection that it affords as a research tool. We also describe variations on the core interface that allow for separate studies in the perception and cognition of creativity in this nontraditional musical system. Finally, we describe a preliminary EEG study that captures several candidates for the neural correlates of creativity as operationalized by listeners' ratings of creativity from musical data obtained using the BP sequencer.

4. THE BP SEQUENCER

The Interface: Inspired by Max/MSP's live.step object and interface, we have created a user interface that iteratively and interactively generates loops, or musical sequences in the Bohlen-Pierce scale, that is intuitive to use with no background in music theory and no previous training, while also being a logical extension of the Improvisation Continuation Task reviewed above for quantifying creativity in musical improvisation [1]. The interface automatically generates tone sequences with fundamental frequencies ranging from 440 Hz to 1320 Hz in 13 possible steps as determined by the Bohlen-Pierce scale [10]. The interface generated tone sequences with a fixed inter-onset interval of 148 ms. Each sequence could be of variable length as determined by the participant. The structure of the sequence (i.e. the specific sequence of pitches in each loop) is repeated continuously, and can be set by the participant in real time using a visual interface as shown in Figure 1.

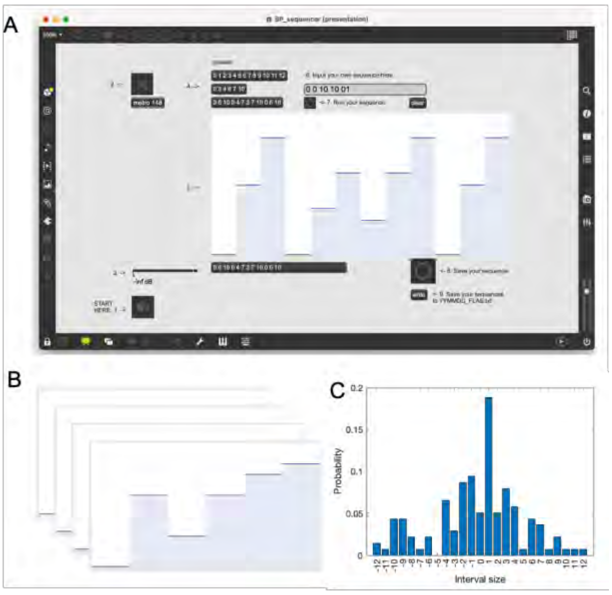

Figure 1. BP sequencer. **A:** Experiment interface for Sequence Generation Task. **B:** Sequences can be concatenated across participants to compute histograms (**C**) from which interval entropy will be computed.

5. EXPERIMENT 1: SEQUENCE PRODUCTION TASK: GENERATING CREATIVE OUTPUT

In a first experiment using this interface, young adult participants from Northeastern University (n = 11) participated in return for course credit. The participant's task is to generate as many creative sequences as possible within five minutes, where a creative sequence is defined as both original and appropriate [12]. Unlike the tasks typically used to measure creativity in music (e.g. improvisation at the keyboard), this sequence generation task is easy and intuitive to individuals across cultures without specialized training. Each participant's generated sequences are saved in a text file, with each sequence represented as a string of integers from 0 to 12 corresponding to the 13 possible steps in the Bohlen-Pierce scale. Sequence files can then be concatenated across all participants to form a larger database of creative outputs (Figure 1B).

These data can be used to extract the following measures from each participant's sequence file for between-subjects analyses: fluency as the number of unique sequences generated by each participant, entropy of interval sizes generated by each participant as a measure of originality, and information content of pitch classes as a measure of surprise (computed from histogram of interval sizes, Figure 1C). Fluency and originality have been previously shown by our lab and others to be related to the neural markers of creativity [13], whereas entropy and information content are known markers of uncertainty and surprise that have been linked to prediction and reward in fMRI and electrophysiological studies [14]–[16].

We expect that participants who generate higher fluency, entropy, and information content will also score higher on fluency and entropy on other non-musical creativity tasks in the lab, such as the Alternative Uses Task [17], supporting the hypothesis that participants who are more creative will generate sequences with higher interval entropy and information content.

6. EXPERIMENT 2: SEQUENCE RATINGS TASK: PERCEPTION OF CREATIVITY

Sequence Rating Task: In a second experiment, another group of young adult participants (n = 10) rated the sequences generated by the first group for creativity. Using a visual slider, participants are asked to rate each sequence for creativity, originality, and appropriateness. Participants are allowed to rate as many sequences as they can within five minutes.

Creativity ratings for each sequence were significantly correlated with the number of unique pitches used in the sequences (r = 0.31, Figure 2A). Among sequences that used all possible pitches, sequences with large intervals and more entropy and information content resulted in a higher creativity rating than sequences with smaller intervals and low information content. For example, Figure 2B and 2C shows two sequences that were generated by participants from Experiment 1. Both sequences used the maximal number of unique pitches (13 in the BP scale). However, the sequence in Figure 2B has larger intervals and a higher entropy of interval sizes, and is rated higher by listeners in Experiment 2. This is consistent with prior research on jazz improvisation [1], [13], [18], in which participants improvised on given sequences on a piano keyboard, and the improvised sequences were subsequently rated by jazz instructors.

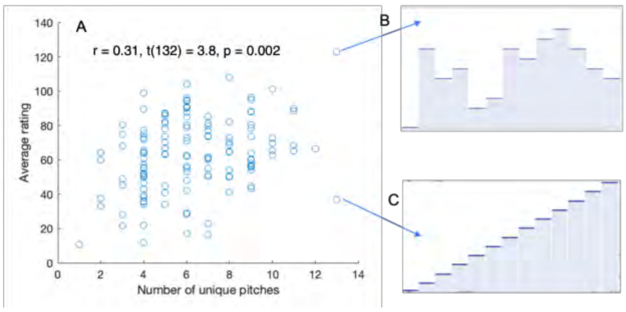

Figure 2. A-C. Preliminary results from Sequence Generation Task.

7. EXPERIMENT 3: EEG SIGNATURES OF CREATIVITY FROM BP SEQUENCER DATA

Experiment 3 aims to relate the perception of sequences generated from the BP sequencer to neural markers of creativity in EEG. Participants were young adults recruited from Northeastern University (n = 6). Each participant listened to each sequence generated from Experiment 1, and rated it for creativity (originality and appropriateness) using the same interface as the Sequence Ratings Task in Experiment 2, with EEG triggers (event time tags) generated by Max/MSP and recorded with the BrainVision system. EEG was recorded with a 64-channel BrainVision actiCHamp system with PyCorder software in a sound-attenuated and electrically-shielded chamber. EEG data was sampled at 1000 Hz and filtered using .5 Hz high pass filter and 60 Hz notch filter for electrical noise. EEG was re-referenced to electrode channels TP9 and TP10, which are relatively stable and commonly used for auditory EEG studies, and corrected for ocular artifacts using Independent Components Analysis (ICA) consistent with most auditory EEG data acquisition protocols [19]. Preprocessing and analyses were done in Matlab with EEGLAB toolbox [19].

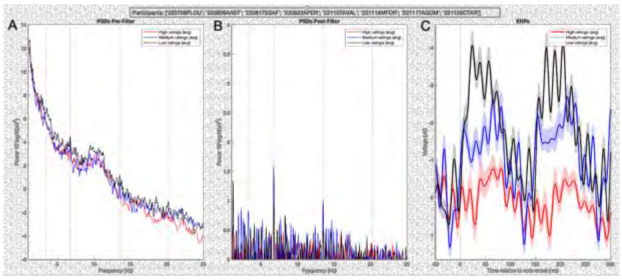

Figure 3. Preliminary results from EEG study in **A.** Frequency-domain, **B.** Steady-state evoked potential, and **C.** Event-Related Potential (time-domain) analyses.

Frequency-based: To assess neural entrainment, power spectral densities (PSDs) were computed over the full length of each EEG channel using Welch's procedure (pwelch in MATLAB) with a 1600 sample window and a 8000 sample overlap. Lower alpha power and higher SSEP at the first harmonic were observed during sequences that received the highest creativity ratings (tertile split) (Figure 3A), suggesting less boredom and higher entrainment to the stimulus.

Steady-state evoked potential (SS-EP): As the frequency-tagging technique has previously been used to assess neuronal entrainment to beat and meter [20], we isolated EEG activity in the form of steady state evoked potentials (SS-EPs) specifically at the note rate, which is set at 148 ms per note (6.76 Hz) for our perception task. Starting from the frequency-based results from above, the broad-band frequency activity was removed by subtracting, at each bin of the frequency spectra, the average amplitude measured at neighboring frequency bins (two frequency bins ranging from −0.15 to −0.09 Hz and from +0.09 to +0.15 Hz relative to each frequency bin). A prominent SSEP was observed at the note rate of 6.76 Hz (corresponding to the inter-onset interval of 148 ms) and its harmonic of 13.5 Hz (Figure 3B), confirming that our task elicits robust neural entrainment to the beat frequency.

Event-Related Potential (ERP): In addition to assessing frequency-based EEG markers of creativity, we computed Event-Related Potentials (ERPs, or electrical fluctuations that are uniquely related to the event of interest [21]) to tones in sequences that were rated as highly creative against sequences that were rated as medium in creativity. Figure 3C shows ERPs of the highest-rated tertile of trials (red) against the medium-rated tertile (black). A persistent difference in ERP was observed between high, medium, and low ratings, from less than 10 ms after tone onset throughout the duration of the time window being analyzed (Figure 3A). Sequences that were rated low in creativity showed the most negative waveforms, whereas sequences that were rated high in creativity showed the least negative waveforms. Negative waveforms during auditory processing, also known as the processing negativity [22], have been identified as the mismatch negativity (MMN), a negative waveform observed in response to unexpected or unpredicted tones given a context [23]–[25]. Results are consistent with the link between unexpectedness and creativity: while highly predictable sound sequences may be perceived as uninspiring, and highly unpredictable sound sequences may be perceived as negative prediction error (in the sense that the participant's mind is unable to form a predictive model of how the sequence would go), it is the slightly unexpected sequences that elicit positive prediction errors, and are linked to higher creativity ratings. These neural markers can thus be coupled with behavioral testing and music technology to enable a better understanding of musical creativity.

8. CONCLUSIONS

We designed a unique user interface for collecting data on musical creativity, using the non-standard tuning system of the Bohlen-Pierce scale. In three experiments, we begin to address questions related to musical creativity as it relates to originality and appropriateness, and we relate the perception of musical creativity to brain-based measures as characterized by EEG. The BP scale is not a commonly used musical system in any culture; thus a sequencer that is built on the BP scale is equally accessible to those with varying levels of experience in different musical systems around the world, rendering it similarly useful for someone from the Western musical tradition and from other traditions, such as Chinese pentatonic or Indonesian heptatonic musical traditions. Furthermore, since Max/MSP is a platform-independent programming language with free runtime versions, a Max/MSP-based user interface that is quick to learn can be scalable in the future for massive online studies. The current studies, though using only small sample sizes, are a step towards this goal. Taken together, we believe that the BP sequencer is a platform-independent, relatively training-independent tool that lowers the barrier-to-entry in neural and cognitive assessments for musical creativity. The code for these tasks are freely available at https://github.com/mind-lab-bos/BPsequencer, along with written instructions and video tutorials.

9. REFERENCES

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