Practice Makes Too Perfect: Fluctuations in Loudness Indicate Spontaneity in Musical Improvisation

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while spontaneity is often a desirable quality in music performance, the objective musical features that characterize genuinely spontaneous performances are unclear. We addressed this issue by recording pianists' keystroke intensity and timing as they produced improvised jazz solos and rehearsed imitations of these solos. Results indicated that the entropy of keystroke intensity was reliably highest for improvisations. Corresponding effects for timing were less consistent. The effects observed for intensity may reflect irregularities in force control associated with relatively wide variations in the performer's (un)certainty about upcoming actions during real-time musical invention. Related fluctuations in loudness may provide listeners with cues to musical spontaneity, thereby affecting aesthetic evaluations of performance quality.

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Spontaneity is often an aesthetically desirable quality in music performance. Listeners generally appreciate expressive variations that make rehearsed interpretations of familiar pieces sound spontaneous, and many are excited by the genuine spontaneity of real-time musical invention in genres characterized by improvisation. The current article is concerned with the latter type of spontaneity, which is widely practiced but poorly understood.

Individuals who skillfully create novel musical material while performing are revered in diverse traditions ranging from Indian raga to free jazz (Nettl & Russell, 1998). Although research has addressed the cognitive processes and brain structures that enable the invention of melodic and rhythmic sequences (e.g., Bengtsson, Csikszentmihalyi, & Ullen, 2007; Berkowitz & Ansari, 2008; Johnson-Laird, 2002; Limb & Braun, 2008), the objective musical features that characterize genuinely spontaneous performances remain unclear.

Skilled improvisers typically have lexicon-like stores of prelearned, idiomatic musical patterns at their disposal. Freedom is exercised, however, in the process of combining and varying these patterns during spontaneous musical invention (Ashley, 2009; Berkowitz, 2010; Pressing, 1988). An improviser's level of certainty about upcoming actions presumably varies as a function of real-time cognitive constraints on this process (see Pressing, 1998). Previous research has shown that errors reflecting momentary decreases in certainty during rehearsed piano performance are associated with reduced keystroke intensity (hence loudness) and disrupted timing (Herrojo Ruiz, Jabusch, & Altenmüller, 2009; Maidhof, Rieger, Prinz, & Koelsch, 2009). Such modulatory effects of certainty on intensity and timing may have several sources, including predictive action control mechanisms that function to correct or reduce the impact of errors (van Veen & Carter, 2006; Wolpert & Ghahramani, 2000) and variations in the time required for memory retrieval (Ericsson & Kintsch, 1995; Newell & Simon, 1972).

The present study sought to identify cues to musical spontaneity by comparing improvised jazz piano solos and thoroughly rehearsed imitations of these solos in terms of their keystroke intensity and timing profiles. We were specifically interested in the entropy (i.e., randomness) of these performance parameters.

Information theoretical approaches to psychology assume that entropy reflects uncertainty in human decision-making and behavior (e.g., Berlyne, 1957a; Koechlin & Hyafil, 2007; Koechlin & Summerfield, 2007). Many of these approaches were motivated by Shannon's (1948) use of entropy as a measure of the information content of communication signals in the field of engineering. When applied to human behavior, entropy can be employed to quantify the uncertainty associated with deciding to execute a particular action from among a set

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of possible actions. Uncertainty and, therefore, entropy vary as a function of the number of possible alternative actions and the (prior) probability of selecting each of these under the given circumstances. If there are numerous equally probable behavioral options, then uncertainty and entropy are high because it is difficult to predict which action will be selected. On the other hand, if there are only a few viable options, then uncertainty and entropy are low.

Research in experimental psychology and neuroscience has demonstrated measurable effects of uncertainty on behavioral and brain processes. Early work by Berlyne (1957b), for example, found that response latencies increased with the number of competing response alternatives in a reaction time task, indicating that high freedom of choice creates conflict in decision making. In a more recent brain imaging study, Yoshida and Ishii (2006) identified prefrontal cortical regions in which neural activity was correlated with the entropy of multiple behavioral options in a virtual maze navigation task, leading the authors to claim that these brain regions are involved in the resolution of uncertainty. It is interesting to note that related patterns of brain activation have since been observed in studies that compared the production of improvised and nonimprovised musical material by pianists (Bengtsson et al., 2007; Berkowitz & Ansari, 2008; Limb & Braun, 2008).

Musicologists, like psychologists, were quick to seize information theoretical concepts such as entropy for use in their analyses, with early papers on the topic appearing in the 1950s (e.g., Meyer, 1957; Pinkerton, 1956; Youngblood, 1958). The primary focus of work in this tradition has been on the description of musical structures in notated scores. Entropy has, notably, been used to characterize diverse musical styles—ranging from Bach chorales to barbershop quartets—in order to understand the compositional process and to explore issues such as the relationship between perceived complexity and aesthetic experience (Huron, 2006; Margulis & Beatty, 2008; Temperley, 2007).

The current study extends the application of entropy measures to behavioral variables related to cognitive and motor aspects of music performance. Specifically, we employed entropy as an index of spontaneity in recordings of improvised and imitated jazz piano melodies. We hypothesized that the entropy of keystroke intensity and timing would be higher for improvisations than imitations due to relatively large fluctuations in the performer's level of certainty during melodic invention. This prediction is based on the assumption (which was arrived at via generalization from the aforementioned work on the effects of uncertainty on performance errors and reaction times) that entropy associated with uncertainty in cognitive decision making can seep through to motor processes that underlie action control.

We were also interested in whether the hypothesized effects of performance mode (improvisation vs. imitation) on the entropy of keystroke intensity and timing would be modulated by familiarity with the musical style and performance manner. To the extent that familiarity facilitates accurate imitation, it may lead to commensurate levels of entropy across performance modes despite differences in certainty. In other words, familiarity with the musical style and performance manner may enable pianists to produce rehearsed imitations that bear the hallmarks of spontaneous improvisations.

Method

PARTICIPANTS

Six male pianists, aged between 23 and 29 years, participated in the study. They had, on average, 11.8 ($SD \pm$ 5.8) years of piano experience, including 6.0 ($SD \pm 4.7$) years of jazz improvisation.

MATERIALS AND PROCEDURE

The sample of jazz piano performances that were analyzed comprised 18 improvised solos and 54 imitations of these solos. These materials were created as follows. First, a professional jazz pianist/composer produced novel backing tracks in three styles (blues ballad, swing, bossa nova). These tracks were recorded in Musical Instrument Digital Interface (MIDI) format via an electronic keyboard (Clavia Nord Electro 2 73). The blues track consisted of three cycles of a 12-bar chord progression (total duration ≈ 160 s); the swing track spanned three 16-bar cycles (duration ≈ 86 s); the bossa nova track had four 16-bar cycles (duration ≈ 112 s). The chord progressions for each backing track are shown in Figure 1.

In the experiment proper, the six participating pianists improvised melodies over these backing tracks—with charts showing the chord progressions in view—on a digital piano (Yamaha Clavinova, CLP150). The tempi and harmonic structures underlying improvisations were thus standardized across pianists. All pianists were experienced at improvising in two of the styles (blues ballad and swing), but reported less experience with the third style (bossa nova).

Each pianist recorded three improvisations per backing track in MIDI format. From these improvisations, excerpts (one per pianist/style) were transcribed by a professional musician using Finale 2005 software (Coda Music Technology). Excerpts lasted around 60 s for blues, and 30 s for swing and bossa nova improvisations. The number

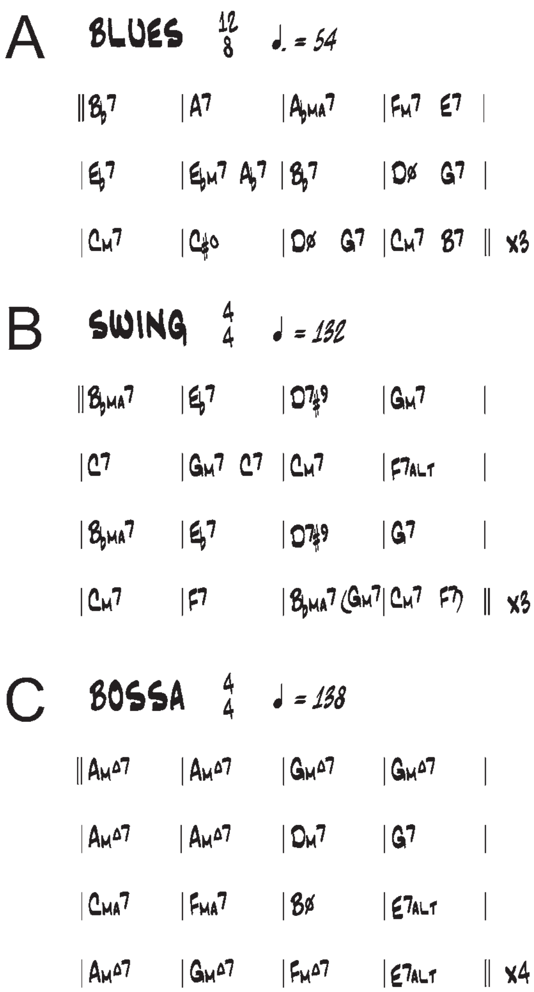

FIGURE 1. Chord progressions for (A) blues, (B) swing, and (C) bossa nova backing tracks. Time signatures and metronome markings (in beats per minute) are also shown. In each chord symbol, the main letter—which may be accompanied by a flat sign (♭) or a sharp sign (♯)—indicates the root tone of a major triad or, if followed by a subscript M, a minor triad. Neighboring symbols indicate alterations to the chord's canonical (triadic) form: 7 = added minor 7th; MA7 or △7 = added major 7th; ALT = altered (raised or lowered) 5th & 9th; ♯9 = raised 9th; O = diminished; Ø = half diminished.

of notes in the excerpts ranged from 86 to 134 for blues, 57 to 89 for swing, and 71 to 107 for bossa nova.

Each pianist returned after 4–12 weeks to imitate the excerpts from their own improvisations (self imitation) and those produced by two of the other pianists (other imitation). Pianists received scanned versions of the transcribed excerpts prior to these imitation sessions. During the sessions, pianists listened to the original improvisations and were allowed unlimited rehearsal. They were instructed to reproduce all audible details.

Several takes of two versions of each transcribed excerpt were recorded in MIDI format. The original improvisation and backing track could be heard (at the same loudness level as during improvisation) while recording the first ('duet') version; the second ('solo') version was accompanied by the backing track alone. Only data from 'solo' imitations that the performers and experimenters considered to be most faithful to the original improvisation are reported here. These imitations were free from note errors, except for occasional discrepancies in the performance of rapid ornaments. (See Supplementary Material for audio examples of improvisations and imitations.)

DATA ANALYSIS

For each recorded MIDI file, Shannon's (1948) information entropy (H)—a measure of the randomness of a probability distribution—was computed for *keystroke intensity* (i.e., force, as indexed by 'MIDI velocity' measured in arbitrary units from 1 to 127) and *keystroke timing* (i.e., the duration of interonset intervals between successive keystrokes). Probability distributions were constructed using 127 bins for keystroke intensity values and 400 equally sized 10 ms bins for keystroke timing. Entropy was calculated for each probability distribution $p(x_i)$ using the formula:

$$H(X) = -\sum_{i=1}^{N} p(x_i)\ln(p(x_i)) \qquad (1)$$

Two sets of analyses of variance were conducted to assess the effects of performance mode (improvisation, imitation) and style (blues, swing, bossa nova) on the entropy of keystroke intensity and timing. Performance mode was treated as a within-pianist variable in the first set, which contrasted improvisations and ('solo') *self imitations*. The second set compared improvisations and *other imitations* (with data averaged across each pair of imitating pianists), and performance mode was treated as a between-pianists variable.[1] The focus of this article is on main effects of performance mode and interactive effects of mode and style, rather than main effects of style.

Results

The analysis of piano performance data revealed that the entropy of keystroke intensity values was higher for improvisations than imitations (see Figure 2A and 2B).

[1] Additional analyses with the same independent variables confirmed that improvisations and imitations did not differ significantly in terms of (1) mean keystroke intensity and interonset timing ($ps > .10$), (2) mean and entropy of articulation (i.e., time intervals between key presses and key releases) ($ps > .05$), and (3) mean and variance of asynchronies between keystrokes in the melodies and nearest neighboring note onsets in the backing tracks ($ps > .05$).

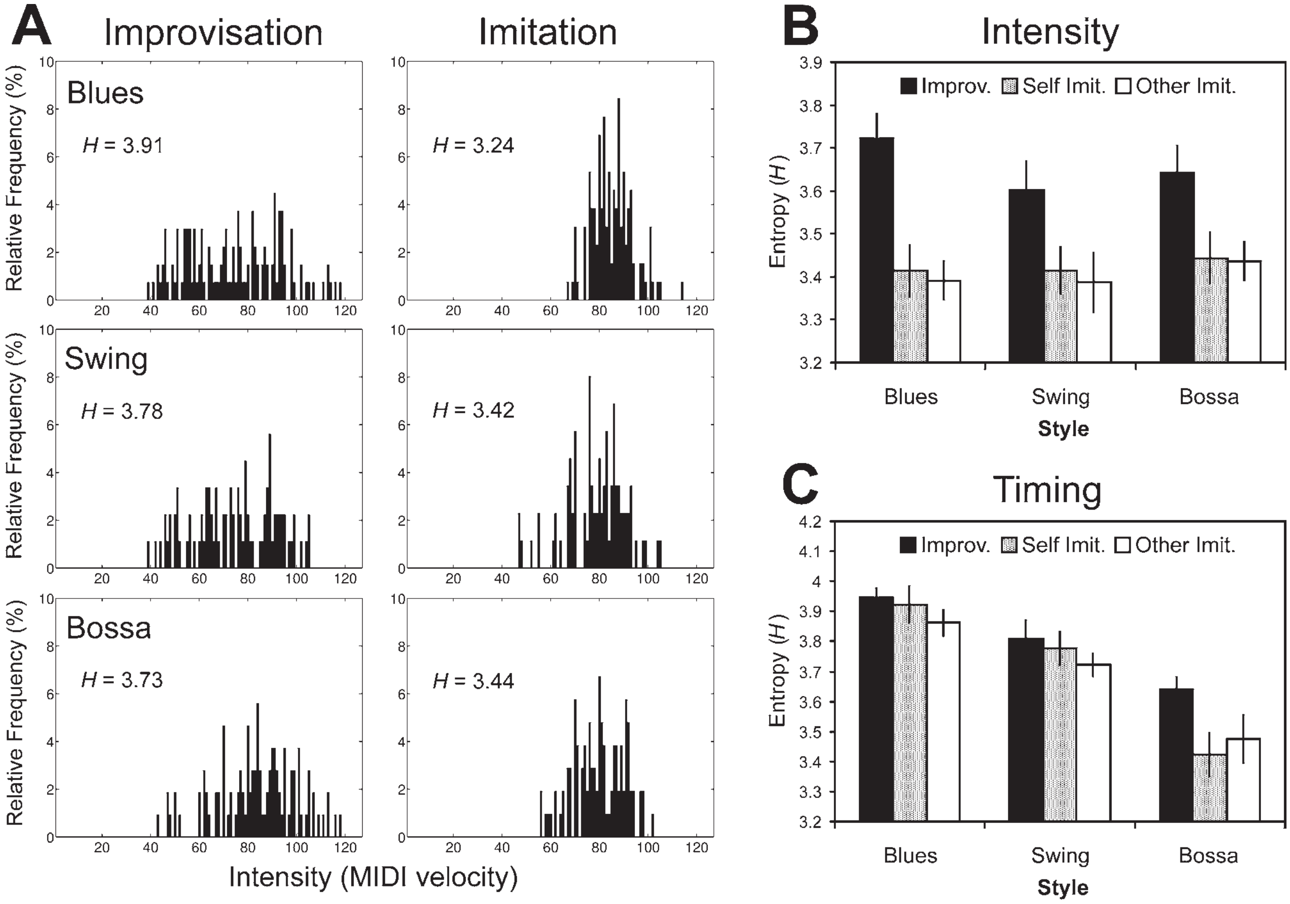

FIGURE 2. Entropy of keystroke intensity and timing in piano improvisations and imitations. (A) Probability distributions of keystroke intensity values for improvised and imitated versions of individual blues, swing, and bossa nova melodies. Flatter distributions indicate higher entropy (*H*). (B, C) Entropy of keystroke intensity and timing for improvisation, self imitation, and other imitation in the three musical styles, averaged across pianists. Error bars represent the standard error of the mean.

Thus, the force with which piano keys were struck—which determines the loudness of produced tones—was relatively variable during improvisation. This effect of performance mode (improvisation vs. imitation) was observed under conditions of self imitation, $F(1, 5) = 12.54$, $p = .017$, and other imitation, $F(1, 10) = 10.52$, $p = .009$. The effect generalized across styles, as evidenced by the absence of statistically significant interactions between performance mode and style for self imitation, $F(2, 10) = 1.53$, $p = .266$, and other imitation, $F(2, 20) = 1.14$, $p = .340$. Similar results were obtained in separate analyses that focused on sequential changes in intensity between adjacent keystrokes (crescendos and decrescendos). This indicates that higher-order intensity relations—not just individual keystroke intensities—had greater entropy during improvisation than imitation. Improvisations thus displayed greater randomness in loudness fluctuation.

The analysis of time intervals between successive keystrokes yielded a different pattern of results (see Figure 2C). Under self imitation conditions, performance mode and style had interactive effects on the entropy of keystroke timing, $F(2, 10) = 14.03$, $p = .006$, indicating that timing variability was reliably lower during imitation than improvisation only in the case of the relatively unfamiliar bossa nova style, $t(5) = 4.47$, $p = .007$. A corresponding interaction was not observed for other imitations, $F(2, 20) = 0.29$, $p = .713$, which were marginally lower than improvisations in terms of entropy of timing across styles, $F(1, 10) = 4.82$, $p = .053$. The fact that these results are less homogenous than those for intensity implies that timing is a less reliable indicator of musical spontaneity. It is particularly noteworthy that spontaneity in rhythmic timing apparently survived rehearsal for self imitation of blues and swing improvisations, wherein both musical style and performance manner were familiar.

Discussion

Our findings indicate that random fluctuations in loudness—but not necessarily timing—characterize spontaneity in improvised music performance. The greater entropy observed in pianists' keystroke intensity for improvisations than imitations can be interpreted parsimoniously by assuming that entropy reflects uncertainty in human behavior (cf. Berlyne, 1957a; Koechlin & Hyafil, 2007). Accordingly, high entropy in keystroke intensity may stem from irregularities in force control associated with relatively wide variations in (un)certainty about upcoming actions during melodic invention. This instability appears to be quenched by practice, irrespective of familiarity with the musical style and performance manner. Randomness in loudness fluctuations therefore provides reliable potential cues to genuine musical spontaneity. Timing seems to be less informative in this regard, perhaps because it can be imitated relatively accurately in the context of familiar performances.

The dissociation observed between intensity and timing may reflect differences in the degree to which nuances in these parameters can be purposefully controlled by the performer. In a case study of spontaneity in highly prepared performances by a concert pianist, Chaffin, Lemieux, and Chen (2007) reported that variability in sound intensity across repeated performances was random, while variability in the rendering of expressive timing deviations was systematic. Chaffin et al. concluded that flexibility in expressive timing enables musicians to make rehearsed performances sound spontaneous. When considered alongside our results, this suggests that spontaneity may be manifested differently during improvisation (random intensity fluctuation) and prepared performance (systematic timing variation). This reinforces the notion that musical spontaneity should not be viewed as a singular construct. It may instead be a multifaceted quality that is characterized jointly by motor variability associated with genuine cognitive uncertainty and by intentional expressive variations that create the impression that rehearsed patterns are being invented on the fly.

Although the current study did not address the perception of musical spontaneity by listeners, we have shown in other work that skilled listeners are able to discriminate between improvised and imitated versions of the same melodies with slightly better than chance accuracy (Engel & Keller, 2011). Related topics for future research include how the aesthetic appreciation of improvised performance is influenced by interactions between objective musical features, such as intensity fluctuation, and listeners' subjective beliefs about the performer's intentions. It may be the case, for instance, that listeners find a certain amount of unpredictable intensity fluctuation to be pleasing when under the impression that a performance of unfamiliar music is improvised, but displeasing if the same performance is believed to be a prepared rendition of a precomposed work. Exploring such hypotheses could bring us closer to understanding the cognitive processes that mediate the communication of spontaneity in musical improvisation.

Supplementary Material

Audio examples of improvised and imitated piano solos (in MP3 format) can be accessed by following the internet links below.

S1: An improvised melody (right stereo channel) played over the blues ballad backing track (left channel); http://static.cbs.mpg.de/Projects/Keller/S1.mp3

S2: An imitated version of the blues ballad improvisation in S1 (which was produced by another pianist); http://static.cbs.mpg.de/Projects/Keller/S2.mp3

S3: An improvised melody played over the swing backing track; http://static.cbs.mpg.de/Projects/Keller/S3.mp3

S4: An imitated version of the swing improvisation in S3 (which was produced by another pianist); http://static.cbs.mpg.de/Projects/Keller/S4.mp3

S5: An improvised melody played over the bossa nova backing track; http://static.cbs.mpg.de/Projects/Keller/S5.mp3

S6: An imitated version of the (self produced) bossa nova improvisation in S5; http://static.cbs.mpg.de/Projects/Keller/S6.mp3

Author Note

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