Mechanical regularity may be an unfair measure when testing musicians because, as noted earlier, music performance is typically characterized by expressive timing variations. A hint at the relevance of this issue can be seen in a tendency to slow down across the three taps in a manner resembling a final ritard (though this feature was not displayed by all participants and was consequently not statistically significant for the group). The possibility that participants were shaping their productions expressively is buttressed by the fact that the third tap of each sequence was executed relatively forcefully, as if participants were accenting the last beat in a musical phrase. In real, communicative music performance, anticipatory auditory imagery may engender a lighter and, qualitatively speaking, more ‘buoyant’ touch, and thereby facilitate the expressive nuances that define artistic excellence (see Repp, 1999c).

**Force and the certainty of intentions**

It was claimed earlier that the quality of a musical performance depends on the degree of certainty in a performer's expressive intentions. Such certainty may vary as a function of a number of factors, including the performer's artistry, technical skill, familiarity with the music, and psychological state. Thus, intentions are presumably more certain in the context of highly prepared performances by competent experts than for spontaneous improvisations by nervous novices. Keller, Weber, and Engel (in press) sought to identify behavioral markers of certainty in musical intentions by analyzing piano performances that were produced under conditions of varying spontaneity; namely, improvised jazz melodies and rehearsed imitations of these melodies. Before proceeding, it must be pointed out that uncertainty should not be viewed in an entirely negative light, since behavioral spontaneity implies some degree of uncertainty. Spontaneity is, of course, an aesthetically desirable quality in music performance (e.g., Chaffin et al., 2007), especially in genres characterized by improvisation (Nettl & Russell, 1998), where risky maneuvers are relished by expert performers and listeners alike.

Skilled improvisers have lexicon-like stores of pre-learnt musical patterns at their disposal. Freedom is exercised, however, in combining and varying these patterns during spontaneous musical invention (Ashley, 2009; Pressing, 1988). An improviser's degree of certainty about upcoming actions presumably varies due to real-time cognitive constraints on this process (see Pressing, 1998). Research on rehearsed piano performances has found that errors reflecting momentary decreases in certainty are associated with reduced keystroke intensity (hence loudness) and disrupted timing (Herrojo Ruiz, Jabusch, & Altenmüller, 2009; Maidhof, Rieger, Prinz, & Koelsch, 2009). Keller et al. (in press) therefore sought to identify cues to certainty and musical spontaneity by comparing improvised jazz piano solos and thoroughly rehearsed imitations of these solos in terms of their keystroke timing and intensity profiles.

Six jazz pianists improvised single-voice melodies on an electronic piano in three styles. All pianists were experienced at improvising in two of the styles (blues ballad and swing), but had less experience with the third style (bossa nova). Tempo and harmonic structure were defined by stylistically appropriate audio backing tracks that were 60-160 s in duration. Each pianist returned later to imitate 30-60 s excerpts from their own improvisations (self-imitation) and those produced by two of the other pianists (other imitation). Notated transcriptions of the excerpts were provided, and pianists were permitted to listen to recordings of the original improvisations, which they were instructed to replicate exactly. Following rehearsal, imitated performances were recorded over the original backing tracks in MIDI format on the electronic piano. MIDI data were later analyzed by computing the entropy (i.e., randomness; see Shannon, 1948) of the probability distributions of values representing keystroke timing (i.e., the duration of inter-onset intervals between successive keystrokes) and keystroke intensity (i.e., force, as indexed by ‘MIDI velocity’ measured in arbitrary units from 1 to 127).

The analysis of timing yielded a complex pattern of results (see Figure 5A). Under self-imitation conditions, performance mode and style had interactive effects on the entropy of keystroke timing, indicating that timing variability was reliably lower during imitation than improvisation only in the case of the relatively unfamiliar bossa nova style. A corresponding interaction was not observed for other imitations, which were marginally lower than improvisations in terms of entropy of timing across styles. The lack of homogeneity in these results across styles and performers implies that timing is not a highly reliable indicator of musical spontaneity or certainty. 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.
The results for force were relatively clear-cut. The entropy of keystroke intensity was higher for improvisations than imitations (see Figure 5B & 5C). Thus, the force with which piano keys were struck was relatively variable during improvisation. This effect of performance mode (improvisation vs. imitation) was observed under conditions of self-imitation and other imitation, and it generalized across styles. 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 — were more variable during improvisation than imitation.

![Figure 5: Entropy of keystroke intensity and timing in piano improvisations and imitations. (A, B) Shannon's entropy (H) of keystroke timing and intensity for improvisation, self-imitation, and other imitation in the three musical styles, averaged across pianists. Error bars represent the standard error of the mean. (C) Probability distributions of keystroke intensity values for improvised and imitated versions of individual blues, swing, and bossa nova melodies. Flatter distributions indicate higher entropy.](image)

Keller et al.'s (in press) findings indicate that random fluctuations in force — 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. Borlyne, 1957; Koechlin & Hafif, 2007). Accordingly, high entropy in keystroke intensity may stem from irregularities in force control associated with relatively wide variations in (im)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. The focus of attention may be relevant to this effect. Specifically, spontaneous improvisation may involve switching between external and internal attentional foci in response to changes in cognitive workload, while rehearsed imitation may be more exclusively externally focused to the extent that musical intentions are relatively highly resolved.

In a follow-up study, Engel and Keller (2019) tested the ability of musically trained listeners to discriminate between improvisations and imitations. Results indicated that the listeners (22 pianists with jazz experience) were able to judge whether a melody was improvised or imitated with an average correct response rate of 55% (range 44-65%), which was significantly better than chance (50%) in statistical terms. An additional analysis aimed at revealing objective features of the performances that influenced listeners’ judgments found that intensity cues accounted for slightly more variance in listeners’ responses (16%) than timing cues (10%). These findings suggest that listeners were able to detect spontaneous fluctuations in the certainty of performers’ intentions primarily on the basis of irregularities in sound intensity associated with random variations in the force with which keys were struck.

**Conclusions**

Performers communicate their expressive intentions about musical structure, motion, and emotion by modulating the timing and force of instrumental and ancillary body movements. The parameters that control movement timing and force are specified by action plans that mediate the translation of mental representations of intended sounds into appropriate motor programs. Although research on music performance has concentrated most strongly on timing, musicians' intuitions and research in kinesiology and sports science suggest that force deserves increased attention. This is justified by music theoretical views concerning dynamic relations between body movements and musical gestures, as well as by
the fact that skilled action generally requires movement force to be controlled in an effective and efficient manner.

The results of two empirical studies were used to illustrate how examining movement force can be informative about cognitive processes that are relevant to music performance. One study indicated that forces applied during movement can be used to gauge the relative roles of auditory and motor imagery during musical action planning. The results of the other study suggested that — during piano performance — irregularities in force control are associated with fluctuations in uncertainty about upcoming actions, and, furthermore, related variations in intensity may serve as a cue used by listeners when evaluating a performer’s spontaneity. In sum, measures of force control go some way towards revealing the contents of a performer’s action plans and the degree of (un)certainty in their musical intentions.

References


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