

Quantifying the Relationship Between Performance Expression and Musical Structure: A Case Study of Chopin Etude Op.10 No.1



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Background

- Performers do not merely reproduce the score; they selectively shape tempo, dynamics, timbre, articulation, and pedaling to reveal the work's formal structure in sound. With advances in digital signal processing and MIR, such expressive decisions can now be quantified.
- Our study examines inter-performer differences in tempo and dynamics for Chopin's Étude Op.10 No.1 and relate the performance data to its A–B–A' form to draw musical inferences.
- We aim to provide quantitative evidence of how individual interpretive choices are realized in performance.

Method

Data collection

- We analyzed Stage-I recordings from the 17th International Chopin Piano Competition (2015), sourced from the Fryderyk Chopin Institute's official YouTube channel, including performances by eight pianists: Seong-Jin Cho, Dmitry Shishkin, Dinara Klinton, Alexei Tartakovsky, Jinhyung Park, Cheng Zhang, Natalie Schwamová, and Rafał Błaszczyk.

Data processing

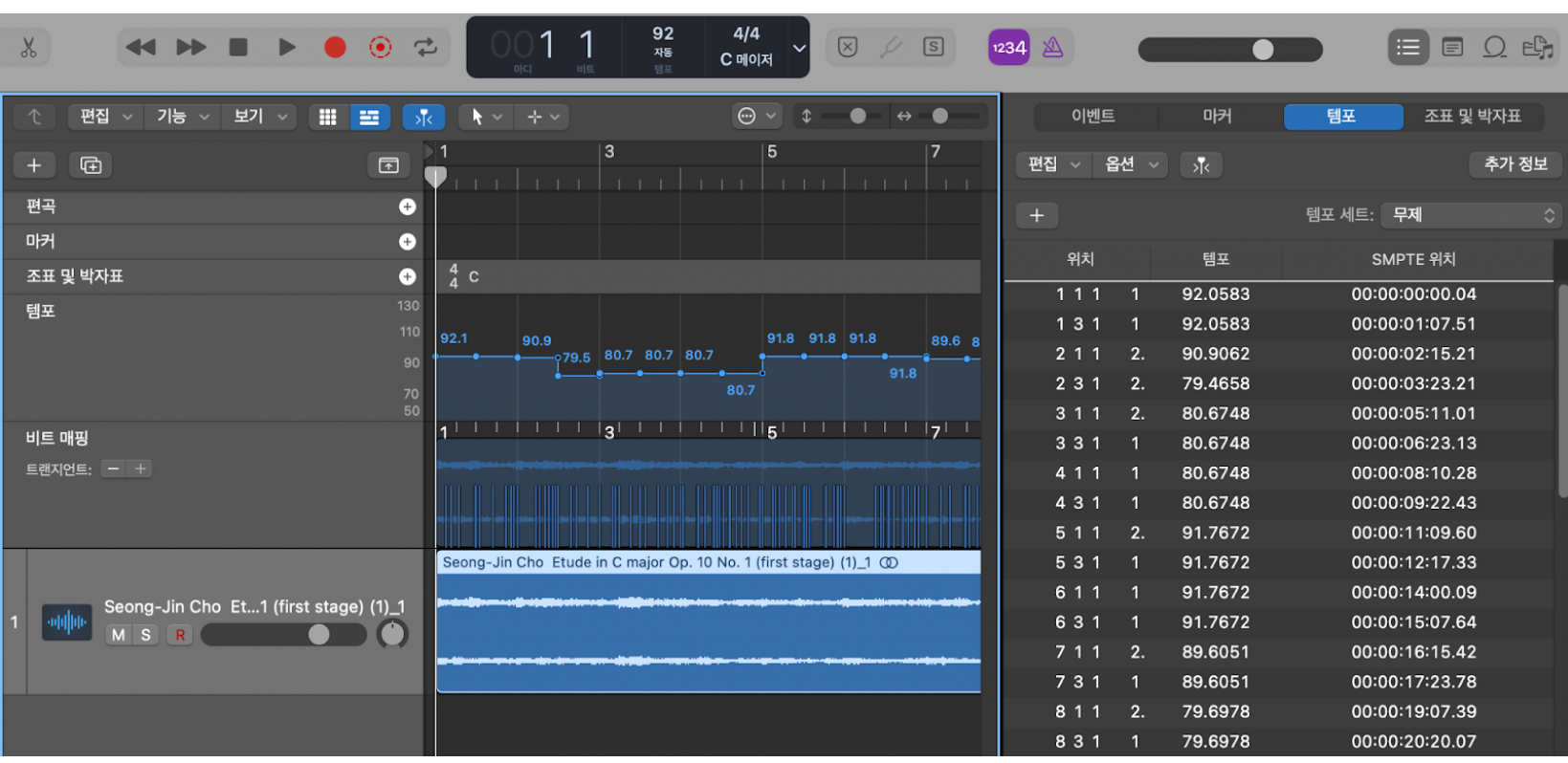
- We extracted audio from live videos of eight pianists performing Chopin's Étude Op. 10 No. 1. After segmenting each performance by bar, we computed tempo (beats per minute, BPM) from inter-beat intervals and dynamics (root-mean-square, RMS) for each bar. To enable cross-performer comparison, we summarized values by section and performer (mean, SD; optionally mean ± SE) and visualized them with line plots. We then related these measures to the work's formal structure (A–B–A') to assess inter-performer differences in interpretive strategy.

Statistics analysis

- For BPM, we manually performed beat-mapping in Logic Pro X (v10.7.9). Using the Event List, we extracted SMPTE timecodes for each bar onset and the corresponding per-bar BPM values, which were then organized in Excel.

- For RMS, audio was converted to WAV using ffmpeg in a Python environment. From each file, bar-level segments were extracted and the root-mean-square (RMS) was computed for every bar. To control extraneous differences (e.g., recording level), RMS values were z-scored within performer before analysis.

Ex.1. BPM Extraction process



Ex.2. RMS Calculation formula

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^N x_i^2}$$
$$z_i = \frac{x_i - \mu}{\sigma}$$

Results

Formal Structure & Performer's Tempo(BPM) Strategy

- Our analysis revealed a close correlation between the ternary form (A–B–A') of Chopin's Etude Op. 10 No. 1 and the performers' tempo interpretations. Specifically, in transitional passages preceding formal sections (mm. 13–16 before B, and mm. 45–48 before A'), all performers consistently decelerated the tempo, clearly articulating structural boundaries. Conversely, the B section (mm. 17–48), characterized by continuous modulations, showed the highest standard error in tempo, indicating it is a point of maximized interpretive diversity.

Competition Ranking & Performance Interpretation

- The higher-ranked group (finalists and stage III participants) had an average tempo of 84.31 BPM, slightly slower than the lower-ranked group's (eliminated in stages I-II) 86.60 BPM. Furthermore, the tempo variability (SD) of the top performers was moderate (approx. 6 BPM), avoiding extremes of rigidity or excessive fluctuation. This suggests that demonstrating flexible tempo control within the structural context of the piece was valued more highly in evaluations than sheer speed and technical brilliance.

Dynamics (RMS) & Musical Expression

- RMS analysis showed that performers employed consistent dynamic strategies at key structural points. For instance, during the crescendo leading to the climax at measure 45 (forte) in the B section (mm. 42-44), the mean RMS value for all performers rose distinctly, faithfully realizing the notated dynamics. In contrast, sections open to interpretation, such as the beginning of the piece (m. 2) or just before the final phrase (m. 69), exhibited the highest standard deviation in RMS, revealing unique dynamic approaches by individual performers.

Figure 1. Mean BPM and Standard Error

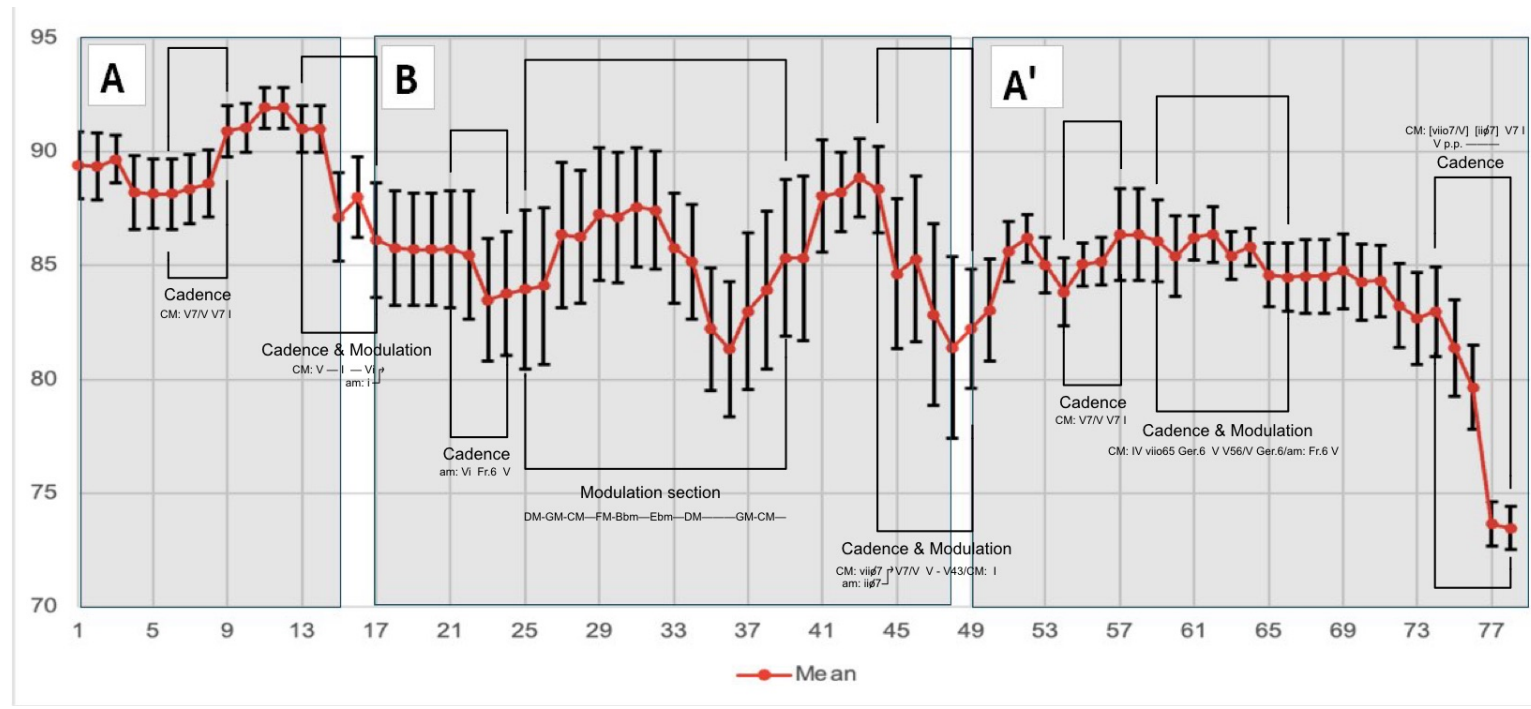


Figure 2. BPM of All Performers and the Mean

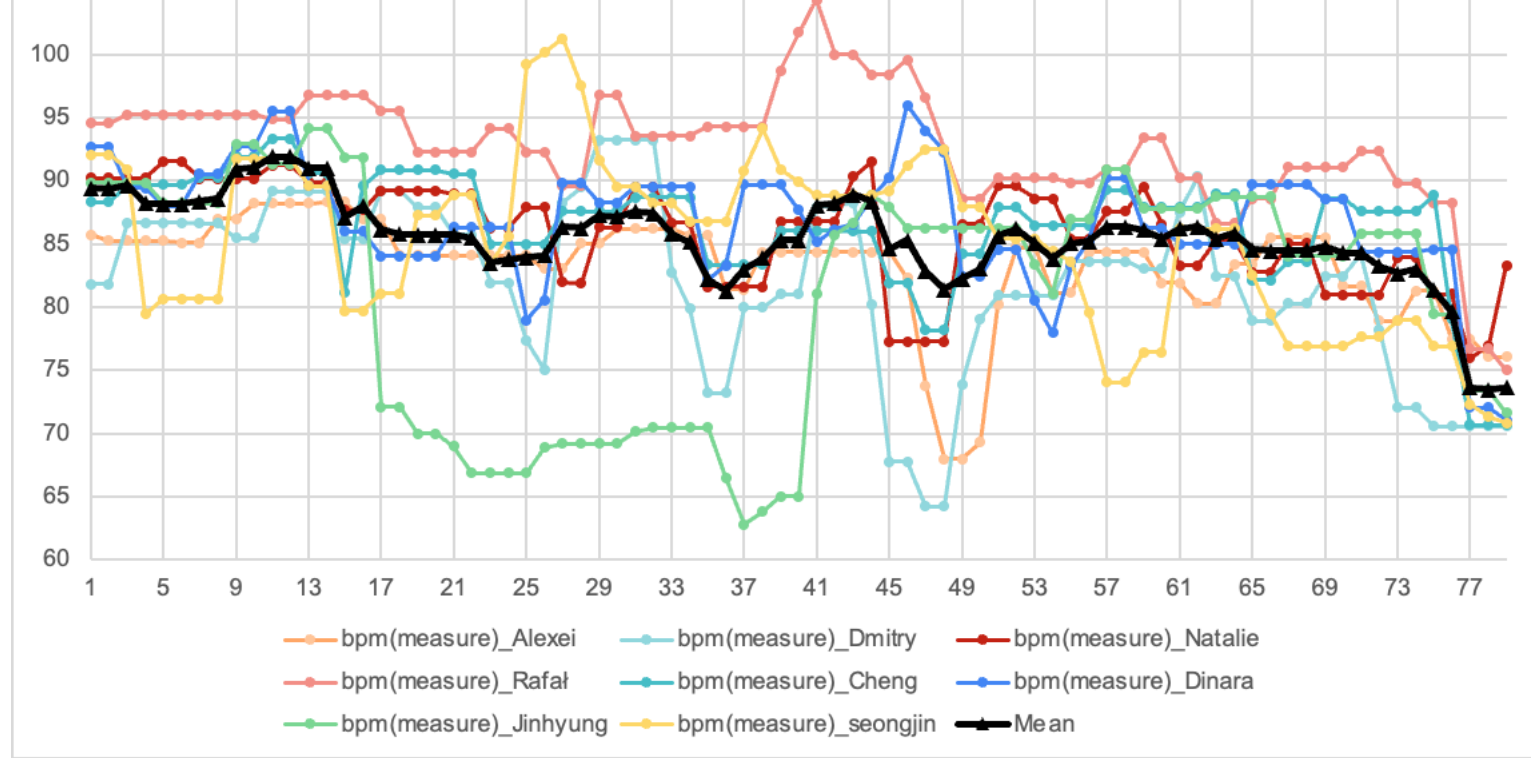


Figure 3. Mean RMS and Standard Error

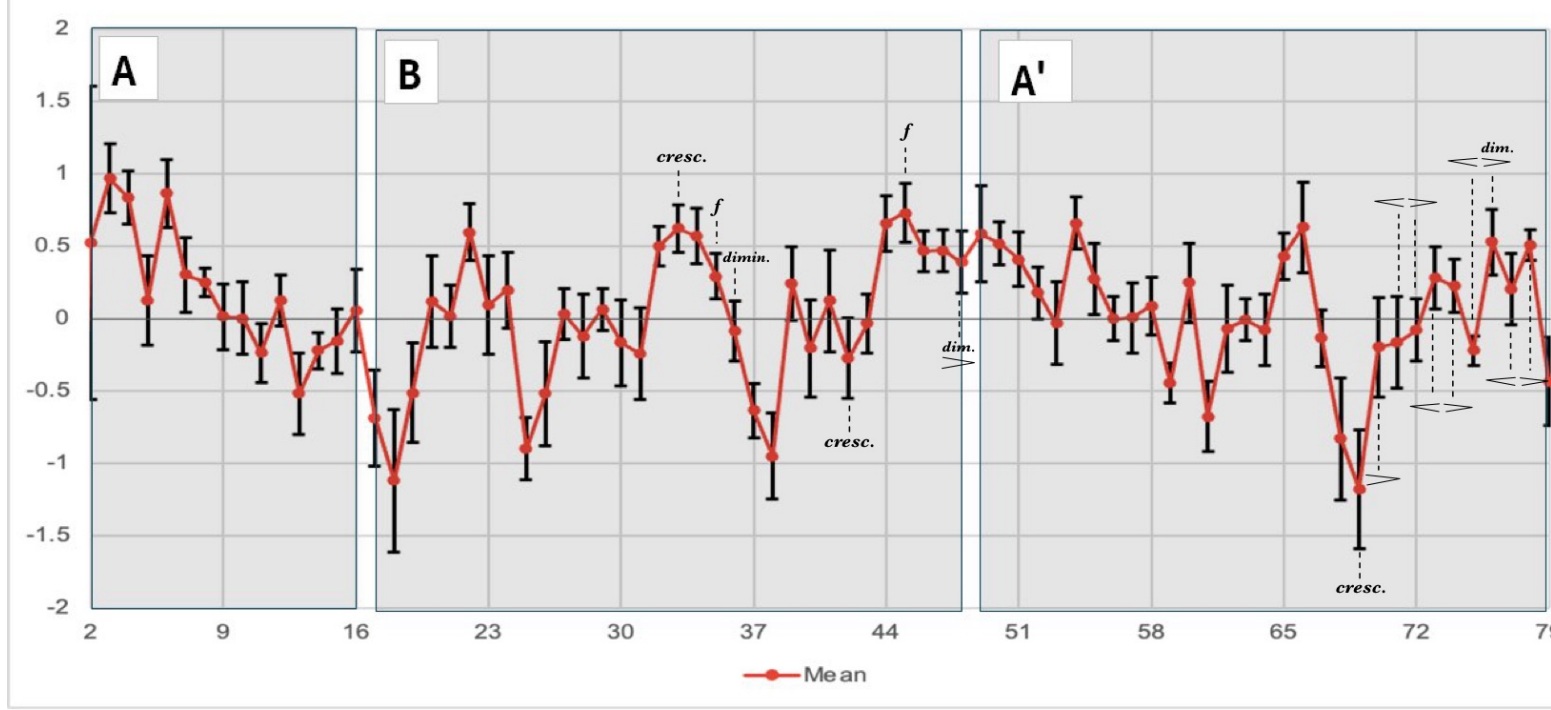
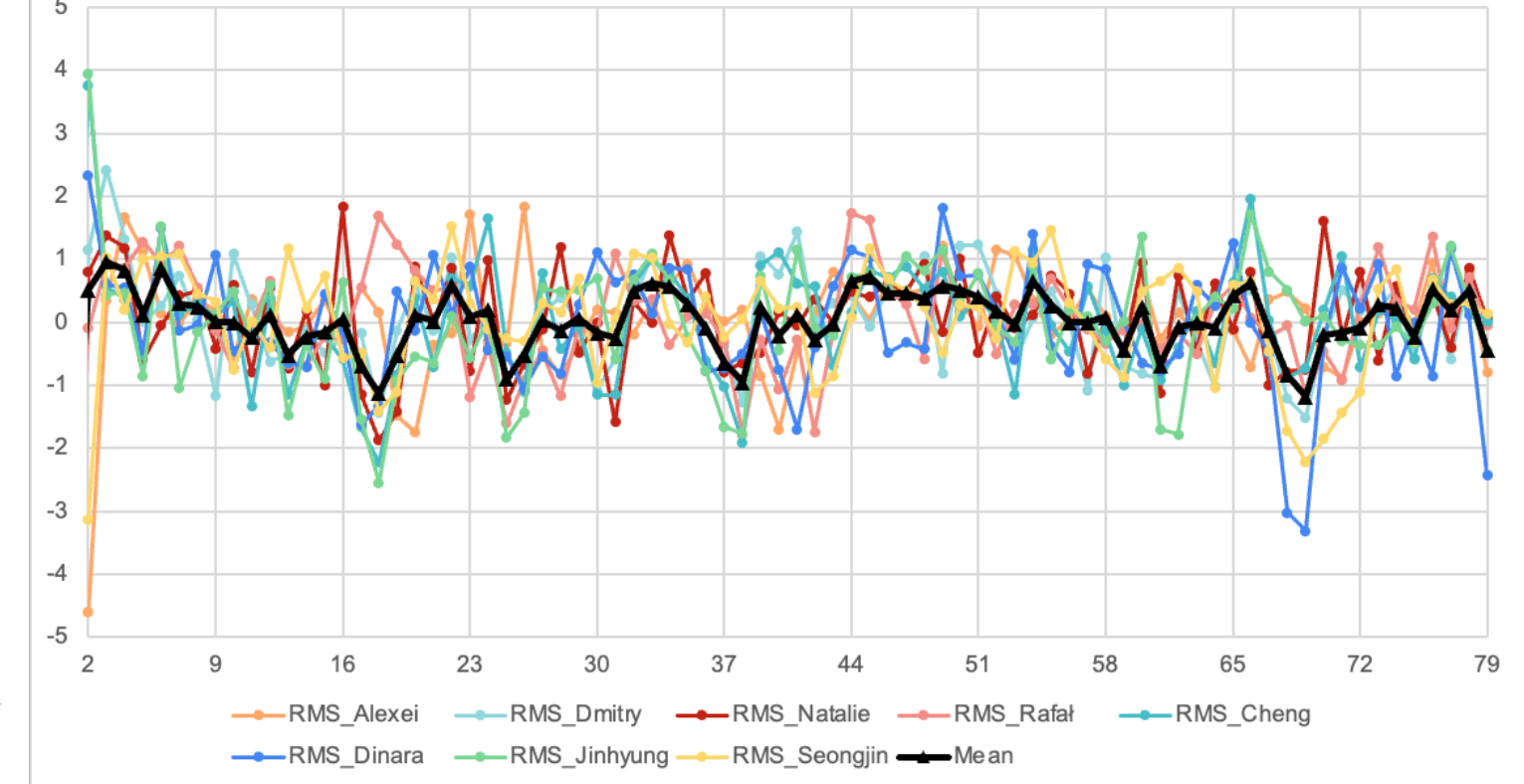


Figure 4. RMS of All Performers and the Mean



Discussion

Link between Structure and Interpretation

- This study demonstrates that performance is an interpretive act that reveals musical structure, not a mere technical display. Performers showed convergent strategies at structurally significant moments, such as decelerating at cadence and applying crescendo at climaxes. Conversely, they exhibited divergent interpretations in harmonically complex sections (e.g., the B section), reflecting a shared sensitivity to the piece's formal structure.

Academic Contribution – Significance of Quantitative Analysis

- By applying DAW-based beat mapping and RMS extraction, this study conducted a quantitative analysis of performance. Unlike traditional approaches that relied heavily on auditory impressions and subjective critique, it provided objective numerical measures to examine interpretive strategies. This methodological shift highlights that performance analysis can move beyond descriptive commentary to become an empirical and reproducible research paradigm.

Limitations and Future Directions

- This study was limited to eight participants from the 2015 Chopin Competition and focused only on tempo and dynamics. Instrument acoustics, performer condition, and factors such as pedaling, articulation, and timbre were not fully considered. Yet these limitations also point to future opportunities for expansion. Broader datasets and multi-dimensional expressive parameters could enable a more comprehensive understanding of performance, providing analytical frameworks applicable to pedagogy, listening, and evaluation in real musical practice.

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