Big Data will analyse the mystery of Beethoven's metronome

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Data science and physics research at the Universidad Carlos III de Madrid and UNED has analyzed a centuries-old controversy over Beethoven's annotations about the tempo (the playing speed) of his

works, which is considered to be too fast based on these marks. In this study, published in the *PLOS ONE* journal, it is noted that this deviation could be explained by the composer reading the metronome incorrectly when using it to measure the beat of his symphonies.

Ludwig van Beethoven (1770-1827) was one of the first composers to start using a metronome, a device patented by Johann Nepomuk Maelzel in 1815. At that time, he started to edit his works with numerical marks with metronome indications. Doubts about the validity of these marks date back to the 19th century and during the 20th century many musicological analyzes were carried out, some of which already pointed to the hypothesis that the metronome was broken, an assumption that could never be verified. In any case, most orchestra conductors have omitted these marks as they consider them to be too fast (Romanticism), whereas since the 1980s, other conductors (Historicism) have used them to play Beethoven. However, music critics and the public described these concerts as frantic and even unpleasant.

Previous scientific research, such as Sture Forsén's study in 2013, has pointed to several defects that may have affected the metronome, causing it to function slower, which would have led the composer from Bonn to choose faster marks than those actually proposed. In order to validate this explanation, researchers from the UC3M and UNED have systematically compared the metronomic marks with contemporary interpretations. This requires physical skills to model the metronome mathematically, analyze data, computing, usability, and, of course, music skills. Overall, they have analyzed the tempo and its variations for each movement of 36 symphonies interpreted by 36 different conductors, a total of 169 hours of music.

"Our study has revealed that conductors tend to play slower than Beethoven indicated. Even those who aim to follow his directions to the letter! The tempi indicated by the composer are, in general, too fast, to

the point that, collectively, musicians tend to slow them down," says Iñaki Ucar, one of the authors of this research, data scientist at the UC3M's Big Data Institute, and clarinetist. This slowing down follows, on average, a systematic deviation, so it is not random, but conductors tend to play consistently below Beethoven's marks. "This deviation could be explained by the composer reading the scale of the apparatus in the wrong place, for example, under the weight instead of above. Ultimately, this would be a problem caused by using new technology," says Almudena Martín Castro, the other author of the study, user experience designer and pianist, who carried out this research within the framework of her Bachelor Thesis for her Degree in Physics at UNED.

In this study, researchers have developed a mathematical model for the metronome based on a double pendulum, perfected with three types of corrections which take the amplitude of its oscillation, the friction of its mechanism, the impulse force, and the mass of its rod, an aspect that had not been considered in previous work, into account. "With the help of this model, we developed a methodology for estimating the original parameters of Beethoven's metronome from photographs that are available and the patent outline," the work explains. In addition to this, they dismantled a modern metronome to measure it and use it to validate both the mathematical model and methodology.

The researchers tried to identify a "break" in the metronome that gave rise to the slow tempi usually followed by musicians. They tried to change the metronome's mass (it may have been damaged and a piece may have fallen off), move it onto the rod, increase the friction (the metronome may have been poorly lubricated) and even testing the assumption that the apparatus may have been misplaced, leaning over the piano while the composer was creating his music. "None of the hypotheses matched what the data told us, which is a homogeneous slowdown in the tempi on the entire scale. Finally, we considered the fact that the deviation matches the size of the metronome's weight

exactly, and we also found the annotation '108 or 120' on the first page of the manuscript for his ninth symphony, which indicates that the composer doubted where he was reading at least once. Suddenly, it all made sense: Beethoven was able to write down a lot of these marks by reading the tempo in the wrong place," they explain.

This methodology could be applied when investigating the work of other classical composers, as they are able to extract the tempo from a musical recording and clean up the data so they can be compared. "Studying the relationship between the tempo played and marks from other composers would be very interesting, or even looking for the 'correct tempo' for composers who did not leave any metronomic marks. Is it possible that there is an average tempo at which people usually interpret Bach's fugues, for example?" they ask.

More information: Almudena Martin-Castro et al. Conductors' tempo choices shed light over Beethoven's metronome, *PLOS ONE* (2020). DOI: 10.1371/journal.pone.0243616

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