Reconsidering Metronomic Precision: Lessons from the Thyratron

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Since its invention in the late eighteenth century, the metronome has exerted a growing authority over conceptions of musical pulse in Western art music. Musicians' deference to a precise mechanical beat represents a significant departure from earlier conceptions of musical pulse, which framed it as an artistic creation of the performer rather than a measurable, objective standard. For students and professional musicians in the present day, pursuit of metronomic precision using a fallible human body is entangled with several factors contributing to the phenomenon of Music Performance Anxiety.

Following Marshall and Eric McLuhan's tetrad theories, which frame the retrieval of obsolescent media as a vector for creating new meaning, this article considers three early electromechanical metronomes, interrogating their idiosyncrasies and inaccuracies as inadvertent gestures toward a concept of musical precision not measured by its alignment with digitally mediated standards. Instead, this article proposes that the innate possibility of variance within obsolete analog technologies can cultivate a more flexible and attentive engagement between the performer and the machine. In turn, this consideration of obsolete metronome technologies illuminates paths forward for more flexible and adaptive musical pulse training using digital tools.

Keywords: metronome, music technology, music pedagogy, pulse, tempo, Western Art Music

In his 1752 instructional treatise *Versuch einer Anweisung die Flöte traversiere zu spielen*, Johann Joachim Quantz (1697–1773) outlined a scheme for determining musical tempo which, though it references a familiar corporeal phenomenon, seems alien to twenty-first-century musical aesthetics:

> The means that I consider most useful as a guide for tempo is the more convenient because of the ease with which it is obtained, since everyone always has it upon himself. It is *the pulse beat at the hand of a healthy person.* I will attempt to give instructions as to how each of the various distinguishable tempos can be determined without great

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> difficulty by regulating yourself with it. Indeed, I cannot boast of being the first to come upon this device [...].[1]

Quantz was a product of the era of *tempo giusto,* the prevailing belief that the "meter, signature, note values, and character of any piece can indicate its natural or 'just' tempo."[2] In the conceptions of Quantz and his contemporaries, musical pulse was a phenomenon generated moment by moment within the musician: on the one hand as a metaphorical or literal echo of one's internal heartbeat, and on the other as a learned affectual response to a musical composition.

Today, the locus of authority for tempo and pulse in Western art music is much less clearly located within the musician. Rather, tempo is now most often described with reference to an external device—namely, the metronome. Though a musical score still reveals its customary affectual clues to an informed performer, the provision of a metronome marking by the composer or editor is typically viewed as a tempo indicator with greater authority than the performer's own inclinations. This tension is evident in, for instance, the ongoing debates among performers and scholars on how to approach Beethoven's metronome markings, which often propose tempi outside of what performers would otherwise choose.[3] Where only a descriptive term for tempo has been included in a score, such as *Allegro* or *Largo*, a performer might consult a chart, typically displayed on the metronome itself, to translate the subjective descriptive term into an objective "beats per minute" (BPM) with which to set the device. After some years of this practice, many performers can equate descriptive tempo terms with BPM ranges with which to set the metronome. This practice diverts attention away from the affective intentions of a composers' tempo descriptor, implying instead that the value of words such as *Allegro* or *Adagio* is in their ability to point toward a BPM range rather than an affect.

In addition to determining the starting tempo of a work, authority is also granted to the metronome as a way of regulating pulse throughout the work. Particularly during practice, performers often strive to stay aligned with a literal or thoroughly internalized pulse derived from a metronome. This is distinct from historical conceptions of pulse, which expected a degree of variation. Even though

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[1] Johann Joachim Quantz, *On Playing the Flute*, trans. Edward Randolph Reilly (Faber and Faber, 1966), 283–4.

[2] Roger Mathew Grant, *Beating Time & Measuring Music in the Early Modern Era* (Oxford University Press, 2014), 125, 201.

[3] See Marten Noorduin, "Transcending Slowness in Beethoven's Late Style," in *Manchester Beethoven Studies*, ed. Barry Cooper and Matthew Pilcher (Manchester University Press, 2023), 214–43; and Clive Brown, "Historical Performance, Metronome Marks and Tempo in Beethoven's Symphonies," in *Classical and Romantic Music*, ed. David Milsom (Routledge, 2011), 255–64.

Quantz proposes his heart pulse idea as a way of better quantifying tempo, he notes, "I do not pretend that a whole piece should be measured off in accordance with the pulse beat; this would be absurd and impossible."[4] By the turn of the twentieth century, practicing *with* the metronome continuously ticking along had become a commonplace recommendation for students.[5] It continues to be such today. The expectation for a musician to be metronomic (or, at the very least, *capable* of metronomic execution) in performance and practice has become synonymous with Western art music performance.[6]

Facilitated by the digital age and its widespread provision of consumer electronics, there are only minimal barriers to obtaining a precise and reliable metronome today. Free smartphone apps or inexpensive digital quartz devices offer musicians a level of precision which, only decades ago, would have been exclusively the domain of specialized scientific instruments. This promise of unerring precision only serves to reinforce the metronome's status as an external authority of pulse. On the other hand, adhering to its unfailing pulse represents a diversion of the performer's attention away from developing the types of expressive, internally derived pulse envisioned or expected by past composers.

The effects of this obeisance to metronomic pulse may also reach further than simply concerns of interpretation. Those who strive (or are encouraged to strive) to match the metronome's thousandths-of-a-second precision with their fallible human bodies face an innately unachievable task; one with clear onramps toward anxiety and self doubt. Recent studies into Music Performance Anxiety (MPA) have highlighted fear of external evaluation, low self-efficacy, and perfectionism as key contributing factors.[7] Each of these factors is at least partially entangled with metronomic conceptions of pulse, practice, and performance.

Using a cluster of mid-twentieth-century electromechanical metronomes as a starting point, this article proposes a more capacious understanding of what constitutes metronomic pulse, in which the device is capable of regularity but may also drift, surge, hiccup, or break. Might these kinds of electromechanical idiosyncrasies be a source of inspiration to undermine notions of the metronome as authority? Might

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[4] Quantz, *On Playing the Flute*, 284.

[5] Ernest K. Adams, *Electric Metronome*, United States Patent US734032A, filed July 30, 1902, issued July 21, 1903, 1.

[6] Alexander E. Bonus, "Maelzel, the Metronome, and the Modern Mechanics of Musical Time," in *The Oxford Handbook of Time in Music*, ed. Mark Doffman et al. (Oxford University Press, 2021), 303–40, here 325.

[7] Dianna T. Kenny, *The Psychology of Music Performance Anxiety* (Oxford University Press, 2011), 50, 72–6.

metronomic *im*precision restore agency to performers caught in an untenable tension between digital precision and their own senses of pulse, musical affect, and physical motion? Though smartphone metronome apps are admittedly unlikely to give way to some kind of resurgent tube-driven metronome industry, I advocate for a renewed consideration of how performers might resist digitally centred notions of musical time and thereby regain creative agency over pulse.

A BRIEF HISTORY OF THE METRONOME

The origins of the metronome can be situated within a wide range of historical timekeeping inventions, with the clearest historical precedent being the chronometer developed by Christian Huygens in 1656.[8] Devices such as Huygens' were bulky, expensive, and regarded mostly as curiosities. Prefacing his ideas of timekeeping via heartbeat, Quantz expressed suspicion about the utility of a device similar to Huygens'.[9] An 1815 invention by Dietrich Nikolaus Winkel was the first to miniaturize a chronometer mechanism to a convenient size, a design which was subsequently pirated and commercialized by Johann Nepomuk Maelzel. The advent of this "new" metronome, popularized through Maelzel's entrepreneurial verve, marked the moment at which the device gained significant influence over Western art music. As a marketing method, Maelzel sent two hundred free metronomes to high-profile composers. Prominent figures including Antonio Salieri, Muzio Clementi, Giovanni Battista Viotti, Luigi Cherubini, Louis Spohr, and Ludwig van Beethoven all took to the device, some of them committing to provide tempi using Maelzel's measurements on all future compositions.[10] This rise of widespread metronome usage accelerated the end of *tempo giusto* as the predominant model of tempo. In so doing, conceptions of tempo shifted partially away from something which a performer might judge according to their artistic impulses and training towards something which could be–and was–expressed and enshrined in objective, scientific terms.[11]

The early reception of Maelzel's metronome was generally positive, but its earliest preferred applications were limited. For example, François-Joseph Fétis

[8] Anders Engberg-Pedersen, "The Sense of Tact: Hoffmann, Maelzel, and Mechanical Music," *The Germanic Review: Literature, Culture, Theory* 93, no. 4 (2018): 351–72, here 364.

[9] Quantz, *On Playing the Flute*, 283.

[10] Myles W. Jackson, "From Scientific Instruments to Musical Instruments: The Tuning Fork, the Metronome, and the Siren," in *The Oxford Handbook of Sound Studies*, ed. Trevor Pinch and Karin Bijsterveld (Oxford University Press, 2011), 201–23, here 211–2.

[11] Grant, *Beating Time*, 125, 201.

explicitly described the metronome's role as a way to communicate tempi between composer and performer rather than something which would govern performance measure by measure.[12] Hector Berlioz, who was quite keen to adopt the technology in general, advised a hypothetical conductor: "I do not mean to imply that he must copy the metronome's mathematical regularity; any music done that way would be stiff and cold, and I doubt that one could maintain such level uniformity for many bars. But the metronome is, all the same, excellent to consult in order to establish the opening tempo and its main changes."[13]

Although the metronome enjoyed only modest technological innovations through the remainder of the nineteenth century and into the early twentieth, it gradually gained new applications. Instead of simply transmitting the composer's intended starting tempo as Berlioz described, it came to be used as a way to maintain tempo during practice. By 1903, inventor Ernest K. Adams filed a patent for an electric metronome, more or less an electrified version of Maelzel's wind-up mechanism, describing how:

> In the study of music the metronome has come to be an important element not only in determining the tempo that a certain composition shall be played at, but in aiding the student in technical exercises to maintain a precision of rhythm in any tempo from a *largo* to a *presto*. There is, however, a disadvantage in the present marketable types, that consists in the necessity of stopping frequently and often in the middle of a difficult passage to wind up the barrel-spring of the device.[14]

Adams may have simply been trying to market the advantages of his electric device, but a tendency toward leaving the metronome running during practice is seen in multiple sources dating from the turn of the century through to the present day.[15] A 2012 study is one of several confirming how this practice remains a major factor of music learning for children and youth today, describing how metronome use even increases as students develop their expertise.[16] Alberto Acquillino and Gary Scavone note that a

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[12] Grant, *Beating Time*, 206.

[13] Hector Berlioz, *Berlioz's Orchestration Treatise: A Translation and Commentary*, trans. and ed. Hugh Macdonald (Cambridge University Press, 2002), 339.

[14] Adams, *Electric Metronome*.

[15] Marc Moskovitz, *Measure: In Pursuit of Musical Time* (Boydell Press, 2022), 252–7.

[16] Susan Hallam, Tiija Rinta, Maria Varvarigou, Andrea Creech, Ioulia Papageorgi, Teresa Gomes, and Jennifer Lanipekun, "The Development of Practising Strategies in Young People," *Psychology of Music* 40, no. 5 (2012): 652–80, here 670.

majority of current music-pedagogy apps centre the metronome, affirming its high-profile role as a training tool and its synonymy with present-day pedagogy.[17] In my own performance training experience, working with a metronome in order to learn new compositions was considered perfectly routine, recommended to myself and colleagues by countless teachers in lessons, masterclasses, and postsecondary education from childhood through to doctoral studies. The metronome has become a universal device in Western classical music pedagogy and practice, ticking away outside the view of the audience. In the words of Roger Mathew Grant, "if the bodies of performers and their instruments are the media through which we experience musical sound, the metronome's technique for tempo mediates their mediation."[18]

As Alexander Bonus compellingly describes in his account of the metronome's effects on Western classical music culture, "the metronomic musician can be considered a regular, if not a positive, exemplar of our modern performance culture."[19] He continues: "the modern act of accurately performing to an automatic tempo (i.e., 'mechanical execution') began in earnest as a scientific-industrial procedure, not an artistic imperative."[20] Finally, Bonus describes the manner in which metronomes lastingly relocated notions of the source of timing and rhythm from the self outwardly onto an external device.[21] An editorial submitted by a pleased parent to the December 1895 issue of *The Christian Science Journal* neatly captures a growing authority of the metronome in music education: "Now there could be no question whether [her child's performance] was right or wrong. If it agreed with the [metronome] it was right: if it disagreed it was wrong and there could be also no offense."[22] The same author goes as far as using the metronome's unerring external precision as a metaphor for divine spiritual guidance, echoing Bonus's assertion that automatic, systematic, and less individualized behaviour had, in the context of Industrial Age thinking, become a social virtue and not "stiff and cold" as Berlioz had earlier characterized it.[23] Recounting his childhood lessons, virtuoso pianist Jeremy Denk further describes a moralistic aspect to metronomes which is likely to resonate with many former child students: "For my childhood teachers, freedom and laziness

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[17] Alberto Acqiulino and Gary Scavone, "Current State and Future Directions of Technologies for Music Instrument Pedagogy," *Frontiers in Psychology* 13 (2022): 6.

[18] Grant, *Beating Time,* 207–8.

[19] Bonus, "Maelzel," 325.

[20] Bonus, 323.

[21] Bonus, 327.

[22] H. L. B., "A Lesson from the Metronome," *The Christian Science Journal,* December 1895, 376.

[23] Bonus, 322–3; and Berlioz, *Orchestration Treatise*, 339.

were connected. To be disciplined was to be strict. There was no such thing as disciplined departure. I was allowed to play without the metronome only if I promised to be good—a musical parole."[24]

The prevalence of metronomic ideals, coupled with the impossibility of truly matching metronomic precision with a fallible human body, creates anxiety and self-doubt for those working alongside the metronome today. Contemporary digital metronomes and metronome apps promise that, short of catastrophic failure of the device altogether, their quartz- or microprocessor-regulated pulse will never vary, can be set to vanishingly small increments of precision, and may furnish a wide variety of clicks, beeps, and buzzes to most clearly assert their pulse on the performer. Unlike the suspicions of Béla Bartók that he possessed an inaccurate metronome,[25] musicians today have no reason to suspect that their metronomes meet anything less than the very highest standards of temporal precision. It follows that, if authority of pulse is bestowed upon such an unfailing device, then any discrepancy between the device and a musician must be the musician's error and their responsibility to correct. In Western art music settings like conservatory recitals, orchestral auditions, and competitions, adjudicators often see this as one of the few objective parameters by which to assess a performance. In contrast to the difficulties of evaluating highly subjective factors like expression, tone quality, or even intonation, the metronomic ideal promises that, if nothing else, a performer's tempo can be assessed against a common objective metric, namely the regularity of the metronome.

MUSIC PERFORMANCE ANXIETY

Music Performance Anxiety (MPA) has attracted considerable study from music scholars and psychologists, owing in part to its detrimental effects on performers and its unique relationships and contradistinctions to other anxiety disorders. In defining the circumstances which lead to MPA, Dianna Kenny identifies evaluative performance scenarios as a strong factor. She also notes the leading roles that perfectionism and low self-efficacy play in MPA prevalence.[26]

Given the emphasis placed on metronomic performance in current pedagogy and audience standards, adherence to the metronome can contribute to MPA risk factors. The motive to evaluate performers by metronomic standards has already been

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[24] Jeremy Denk, *Every Good Boy Does Fine: A Love Story, in Music Lessons* (Random House, 2022), 269.

[25] Moskovitz, *Measure*, 245.

[26] Kenny, *Psychology of Music Performance Anxiety*, 50, 72–6.

discussed, and performers' perfectionism regarding steady pulse is enabled by the very concept that tempo and pulse can be objectively perfect, a notion early nineteenth-century metronome users would likely have found nonsensical. Low self-efficacy–that is, low belief in one's capacity to achieve desired outcomes–is linked with occurrence of MPA. Conversely, high self-efficacy is linked with a reduction in MPA.[27] Self-efficacy is also closely tied to one's perceived control over their environment.[28] A belief that the metronome is the sole reference for appropriate pulse may contribute to sensations of both low self-efficacy (e.g., "I don't know if I can maintain a metronomic pulse") and control over the environment (e.g., "My pulse is fallible, so I must defer to the metronome").

The same factors that contribute to MPA also limit performers' experience of flow, a state in which they generally report positive associations about their performance experience.[29] An essential component of flow is the presence of action-awareness merging, in which the act of performing is fully merged with the self, with minimal or no distraction from outside factors.[30] A 2019 paper by Susanna Cohen and Ehud Bodner highlights that of nine components comprising flow, action-awareness merging was the least reported by orchestral musicians, by a strikingly large margin.[31] The cause of this remains a question for further investigation and falls beyond the scope of this article, but it is notable that an orchestral setting requires musicians to entrain their temporal sensibility to the conductor and the surrounding musicians, rather than retaining significant temporal agency for themselves. While a professional conductor will generally not take a strictly metronomic approach, from the performers' perspectives the same challenges to self-efficacy and control over the

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[27] Manli Hu, "Delving into the Structural Model of Students' Music Performance Anxiety, Self-Efficacy, and Motivation Based on a Self-Determination Theory," *Learning and Motivation* 87 (2024): 7–8; and Claudia Spahn, Franziska Krampe, and Manfred Nusseck, "Live Music Performance: The Relationship Between Flow and Music Performance Anxiety," *Frontiers in Psychology* 12 (November 2021): 3.

[28] Kenny, *Psychology of Music Performance Anxiety*, 72.

[29] Spahn et al., "Live Music Performance," 3.

[30] Amélie Guyon, Horst Hildebrandt, Angelika Güsewell, Antje Horsch, Urs Nater, and Patrick Gomez, "How Audience and General Music Performance Anxiety Affect Classical Music Students' Flow Experience: A Close Look at its Dimensions," *Frontiers in Psychology* 13 (2022): 2; and Jeanne Nakamura and Mihaly Csikszentmihalyi, "The Experience of Flow: Theory and Research," in *The Oxford Handbook of Positive Psychology,* ed. C. R. Snyder, Shane Lopez, Lisa Edwards, and Susana Marques (Oxford University Press, 2020), 279–96, here 282.

[31] Susanna Cohen and Ehud Bodner, "The Relationship between Flow and Music Performance Anxiety amongst Professional Classical Orchestral Musicians," *Psychology of Music* 47, no. 3 (2019): 420–35, here 426.

environment are at play as when a metronome is used. The individual must subordinate their own sense of pulse to that of a single external authority.

MPA is a complex phenomenon. It involves many more factors than a performer's relationship with the metronome; performers' concerns about pitch, timbre, or many other aspects of performance may be equally or even more pressing. However, MPA is an indicative example of one set of negative effects the metronome may cause when assigned an overly authoritative role in defining pulse. Even so, a full-scale indictment of the metronome, besides being more than two centuries too late, would overlook its many practical benefits. Metronomes are indeed highly effective as practice tools which quickly illuminate areas in which the performer is tending to speed up or slow down unintentionally. They can also provide a quantifiable way to gradually build up to performing pieces in faster tempi. In the case of many works of contemporary Western art music, like Steve Reich's phase music, the performer's ability to hold a specific, mechanically precise tempo is integral to the execution of the work. Other composers have used the metronome itself as an instrument, as in György Ligeti's 1962 *Poème symphonique* for one hundred mechanical metronomes.

How, then, might we constructively challenge the metronome as the source of temporal authority? How might we thereby restore temporal agency to performers, without losing the many practical benefits for metronome usage or, implausibly, advocating for a Luddite ban on the devices altogether? Given the metronome's entanglement with Western music history through the last two centuries, and its technological developments during that time, certain moments in its history can be fruitfully revisited: landings on the stairway of progress that can be re-interrogated as departure points towards different relationships with the metronome. In the following case studies, I examine several mid-century metronomes through this lens.

CASE STUDY: THYRATRONS, NEON LAMPS, & FAULTY CAPACITORS

In 1946, Walther Anderson filed a patent for the Metronoma, a novel electronic metronome utilizing gas-filled tube circuitry, similar to that used in tube amplifiers and televisions. Advertisements exhorted its "electronic precision" and advanced technology, going on to note that "it can't wear out–can't slow down. The beat is always steady, accurate at any tempo. [...] It uses the thyratron "heart beat" tube developed for radar."[32]

The emphasis on the novelty of the thyratron tube is particularly notable. Electric metronomes as a concept were not new, with patents dating back at least as far

[32] Selmer Inc., "Selmer Metronoma," *The Etude Magazine*, May 1, 1954.

as 1893, when an English patent was filed for a Maelzel-style clockwork metronome furnished with a battery instead of a wind-up spring.[33] By the 1930s, patents had been filed for metronomes which plugged into household mains current for a reliable power supply, but which still employed electromechanical means to regulate the beat.[34] Anderson's use of the thyratron tube in the Metronoma (Figure 1) represented a first step toward current digital metronome technologies in which the beat is, as Bonus terms it, "entirely detached from visible space and natural motion."[35] Instead of the tempo being a derivative of mechanical processes, it now in part derived from the cryptic glow of a silent tube and the invisible charging and discharging of capacitors (again, Figure 1). By referencing the thyratron's role in radar, a novel and positively-viewed technology in post-war America, the Metronoma was also being consciously positioned as a thoroughly contemporary industrial-scientific object, lending weight to its claims of superior precision and reliability.

Yet, in 2022, when a user of the *Antique Radios* internet forum posted about discovering this obsolete device for themselves, a commenter witheringly noted that "I would never use a metronome like that. Considering the variation in tube characteristics, capacitor and resistor tolerance, potentiometer tracking, temperature variation, neon light threshold variation, this thing cannon [sic] possibly be accurate, and accuracy is demanded for this application."[36] Though this commenter's approach to the metronome indicates their general faith in metronomes as authorities, their practical concerns about the Metronoma's components are fair. The performance of gas-filled tubes is susceptible to temperature variations, and the manufacturing standards of virtually all electrical components in the Metronoma had wider variance and tolerances than those of their present-day equivalents. Furthermore, despite the Metronoma's marketing claims that it couldn't wear out or slow down, the analogue electrical components on which it relies are indeed liable to vary or fail. Electrical tubes are consumable objects which deteriorate with use, while the electrochemical properties of mid-century waxed paper capacitors are unstable over long periods, and the contacts on potentiometers corrode over time. In sum, there are a significant number of ways in which the pulse of a given Metronoma could deviate from ideal expectations.

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[33] Moskovitz, *Measure*, 236.

[34] J. H. Morrison, *Metronome*, United States Patent US2048881A, issued July 28, 1936; and Frederick Franz, *Electrically Driven Metronome*, United States Patent US2150967A, filed January 23, 1937, issued March 21, 1939.

[35] Bonus, "Maelzel," 326.

[36] "Thyratron-Driven Metronome," *Antique Radio Forums*, online forum, 2022, accessed August 23, 2024, https://www.antiqueradios.com/forums/viewtopic.php?f=13&t=412071&start=20.

FIGURE 2. *Above, i*nterior components of the Crystalab Metronoma. The neon indicator lamp (*left*) is lit and the thyratron tube (*right*) is glowing dimly; author's collection.

FIGURE 1. *Right,* Crystalab Metronoma; author's collection.

It is important to distinguish between *accuracy* and *precision* before proceeding further with discussing metronome measurements. Accuracy refers to how close data points are to an accepted true measurement (in this case, beats per minute). Precision meanwhile refers to how close measurements are to one another (how consistent the metronome's tempo remains over time). While a modern digital metronome produces accuracy and precision deviations measured in thousandths of a second, a defective clockwork metronome (like those, possibly, owned by Beethoven or Bartók) might produce poor accuracy. What the metronome's dial indicates as 144 BPM, for example, may in fact lead to a sounded pulse of 120 BPM. Precision is of greater relevance here: practicing *with* a metronome presupposes its precision is reliably high, such that one might practice along with it without fear of the tempo deviating. The assumed precision of a metronome is key to its authoritative status. A device with low precision, or at least the *possibility* of inconsistent pulse, could no longer be regarded as an infallible reference point.

In the following examples, I assess four metronomes from the twentieth and twenty-first centuries in order to measure their precision. These metronomes are in original condition, heightening the probability of components being worn, out of specification, or near failure. As a result, I do not claim that these devices' operations in the present are identical to how they functioned when new. Instead, channelling Marshall and Eric McLuhan's tetrad theories, which frame the retrieval of obsolescent media as a vector for creating new meaning,[37] I argue that the devices *as they stand now* might prove a useful departure point for renegotiating the relationship between performers, the metronome, and tempo more generally.

Methodology

Each metronome was recorded while operating for ten minutes, using a Tascam DR-05X portable audio recorder at close range. The resulting 96khz 24-bit WAV audio files were analyzed for the precision of their beats using Sonic Visualiser software with the *Tempo and Beat Tracker* plug-in. In the case of the two metronomes employing thyratron tubes (the Crystalab Metronoma and the Seth Thomas E962-000), the thyratron was allowed to warm up by operating the metronome at its maximum tempo for one minute, as advised by original instructions for the Selmer Metronoma (a rebranded version of the original Crystalab device).

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[37] Marshall McLuhan and Eric McLuhan, *Laws of Media: The New Science* (University of Toronto Press, 1988), 99–100.

The primary metric assessed was the variance in spacing between beats, which reflects the precision of the metronome's measurement of time. This variance was output by Sonic Visualiser as the BPM calculated from the space between two beats, yielding a data set of varying BPM readings. Assessing the accuracy of the metronomes, namely the correlation between the markings on their dial and their actual average BPM, was not a primary goal. All recordings were made with the metronomes manually set to click as close to 60 BPM as possible, with reference to a known 60 BPM source; tests reported between 59.03 and 61.02 average BPM.

The graphs provided in the *Results* section display the BPM calculated for each recorded beat, alongside a line showing the moving average of the BPM over the previous eight beats. This latter metric reflects the fact that a performer is unlikely to respond to a slight fluctuation between just two beats, but is more likely to adjust their performance to realign with the metronome over the course of a greater number of beats.

The Crystalab Metronoma

The first device tested was a Crystalab Metronoma in a wooden case, which appears to retain its original internal components (Figures 1 and 2). A handwritten mark on the interior reads "8950," possibly a manufacturing date code representing August 9, 1950; this date coincides with a stamp on the back panel stating "Pat. Applied For," suggesting that the device predates September 19, 1950, when Anderson's patent was granted.[38] The tempo is provided visually by the flashing of a small neon indicator lamp (Figure 2). Synchronized audible ticking is provided by a small solenoid which strikes a thin, resonant panel of balsa wood; the resonance of this sound can be adjusted via a thumbscrew that adjusts the distance between the striker and the panel.

The Seth Thomas Model E962-000

The second device tested was a Seth Thomas Model E962-000 in a wooden case (Figure 3). A date of March 1968 is printed on the interior. The back panel and internal metal chassis reference U.S. Patent No. 2,522,492, the same patent employed in the Crystalab Metronoma. Relative to the Metronoma, the Model E962-000 has

[38] Walther M. A. Andersen, Electronic Metronome, United States Patent US2522492A, filed May 29, 1946, issued September 19, 1950.

almost identical circuitry but employs a small 2D21 thyratron in place of the Metronoma's older and bulkier 2051 thyratron. The components are slightly

FIGURE 4. *Above,* Seth Thomas Model E962-000; author's collection.

FIGURE 3. *Right*, Franz Electronome; author's collection.

rearranged in physical configuration and the paper capacitors found in the original Metronoma have been replaced by film capacitors.

The Electronome

The third device tested is a Franz Electronome in a Bakelite case (Figure 4), an iteration of a popular model first filed for patent by Frederick Franz in 1937.[39] The dating of this particular device is uncertain, in part because it is missing its bottom panel and in part because its specific combination of dial style with an uncovered neon flashing lamp is inconsistent with other known Electronome models. It probably dates to after 1954, because earlier models do not appear to have included the neon lamp and because it includes a motor-braking feature for which the Franz Company filed for a patent in 1954.[40] In common with other Franz electromechanical metronomes, tempo is regulated via a metal cone attached to a constantly spinning motor. As the tempo dial is adjusted, a rubber wheel is brought into contact with different widths on the metal cone, creating a type of variable transmission. A cam attached to the rubber wheel creates and breaks electrical contact between two wires in order to flash the neon indicator lamp. A small metal clapper may also be engaged or disengaged by the user. When engaged, it taps the beat directly on the interior of the Electronome's Bakelite case. The rubber wheel is susceptible to hardening over time, which might degrade the quality of contact between the rubber wheel and the cone.

The Korg TM-50

The Korg TM-50 was selected as an average example of a mid-quality battery-powered digital metronome (Figure 5, *right*). It is powered by AAA batteries and operates fully digitally via integrated circuitry, an internal speaker, and display of the pulse via a liquid crystal display and a translucent button through which a light-emitting diode flashes. The TM-50 model was first released in the mid-2010s, and derivatives using the same

FIGURE 5. Korg TM-50 digital tuner and metronome; author's collection.

[39] Franz, *Electrically Driven Metronome*.

[40] Franz.

circuitry remain readily available at the time of writing. The TM-50's official specifications cite a "tempo accuracy" of ±0.03%; it is not clear how the manufacturer defined this figure or whether it is meant to refer to accuracy or precision.

Results

Given its electronic quartz mechanism, the Korg TM-50 was predicted to be the most consistent of the tested devices, thereby acting as a control device. As shown in Figure 6 (*below*), its accuracy and precision were very high. Its average tempo was assessed as 59.999 BPM and over the course of the ten-minute sample recording the BPM reported by the Sonic Visualiser software yielded a range of 0.69 BPM and a statistical variance value of 0.069. The tempo recorded is very accurate, but occasional apparent precision fluctuations between 59.43 and 60.12 BPM yielded the sawtooth wave pattern seen in the graph. This recurring sawtooth wave pattern appeared in all outputs and is, in part, a reflection of the calculation algorithms used by Sonic Visualiser's *Tempo and Beat Tracker* plug-in. However, given its predictability and generally limited range, the sawtooth wave pattern does not communicate important information except for where it ceases to be a regular wave pattern at all, such as in the test results of the Metronoma below. Overall, the close adherence of the control test results to the TM-50's settings and specifications confirmed the validity of the test procedure.

The two thyratron models tested, the Crystalab Metronoma and the Seth Thomas E962-000, are essentially identical in circuitry design, notwithstanding cosmetic differences and the slightly different thyratron tube used in the Seth Thomas model. These two models showed the greatest variance of the tested devices. The Crystalab Metronoma yielded a range of 4.40 BPM and a statistical variance of 0.449 (Figure 7); the Seth Thomas yielded a range of 2.79 BPM and a statistical variance of 0.178 (Figure 8). Notably, although both devices had been allowed to warm up, long periods of tempo stability gave way to erratic fluctuations toward the end of each ten-minute testing period. In the case of the Crystalab Metronoma, the eight-beat average tempo (indicated by the solid orange line) fluctuated to a high degree, in a manner which would likely have impacted a performer's adherence to the tempo. The same phenomenon began to occur in the Seth Thomas model but was truncated by the end of the ten-minute testing period. The variations observed in the thyratron device pulses are likely due to partial failure or electrochemical variation in the device capacitors or thyratrons; the lower variance of the Seth Thomas model may reflect the younger age of its constituent components.

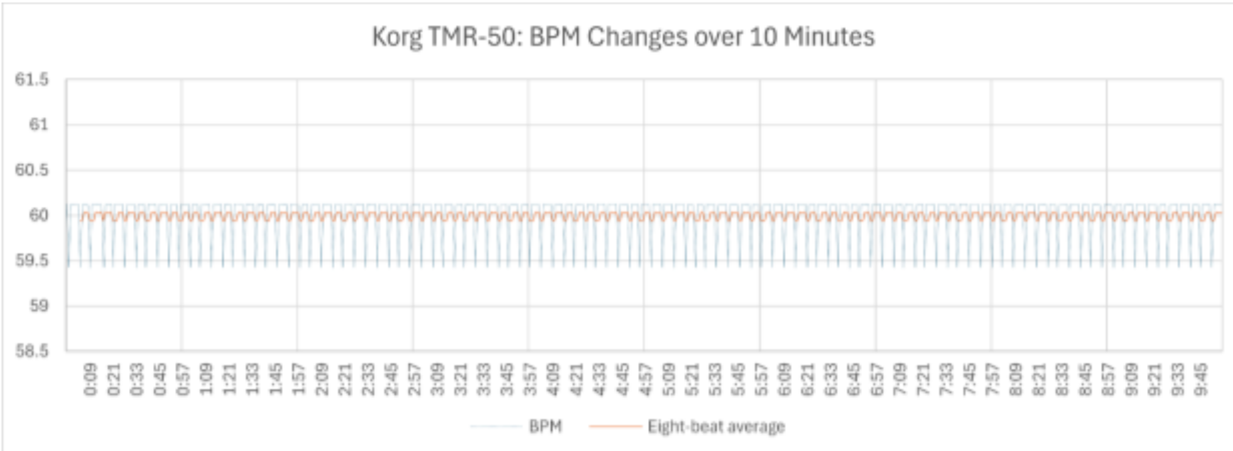

FIGURE 6. Test results, Korg TM-50. (Generated using Sonic Visualiser)

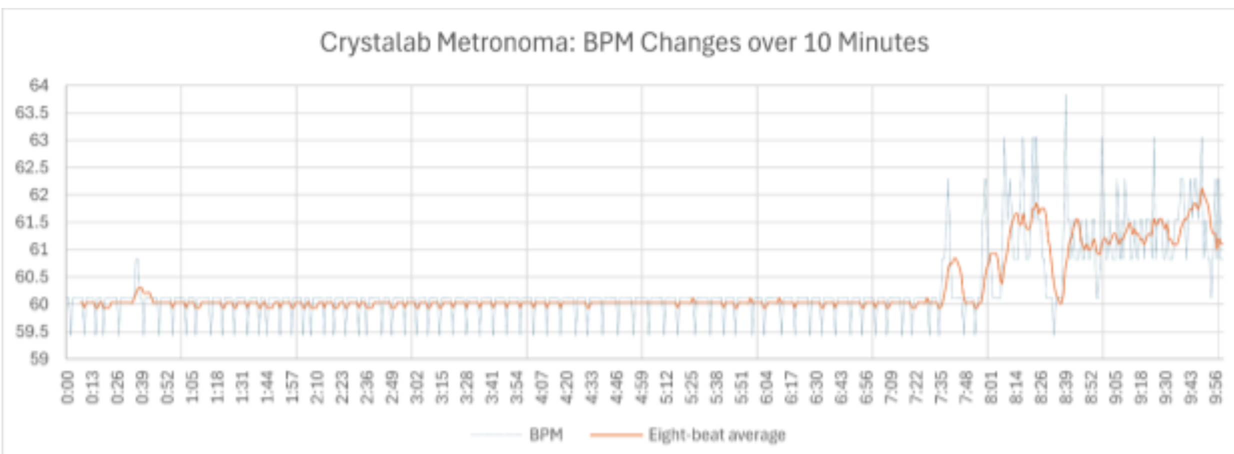

FIGURE 7. Test results, Crystalab Metronoma.

The Franz Electronome's circuitry, which does not rely on thyratrons or capacitors, fared much better than the thyratron-based devices. It returned a range of 0.72 BPM and a statistical variance of 0.102 (Figure 9). In common with the other electromechanical devices tested, its output tempo did not accurately match its dial setting, yielding an average of 61.025 BPM. The sawtooth pattern is more prevalent in this analysis than that of the Korg TM-50, but the eight-beat average tempo returned a

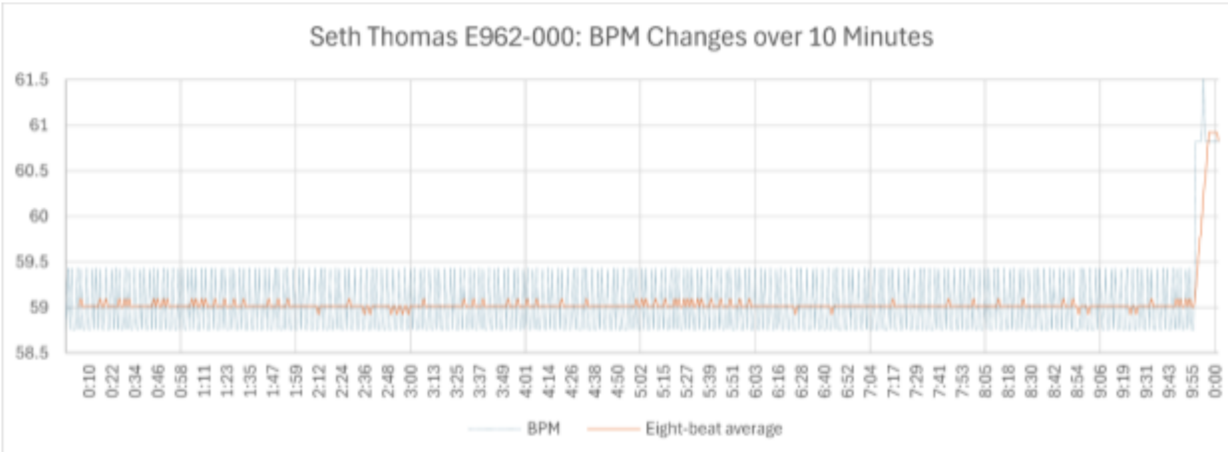

FIGURE 8. Test results, Seth Thomas Model E962-000.

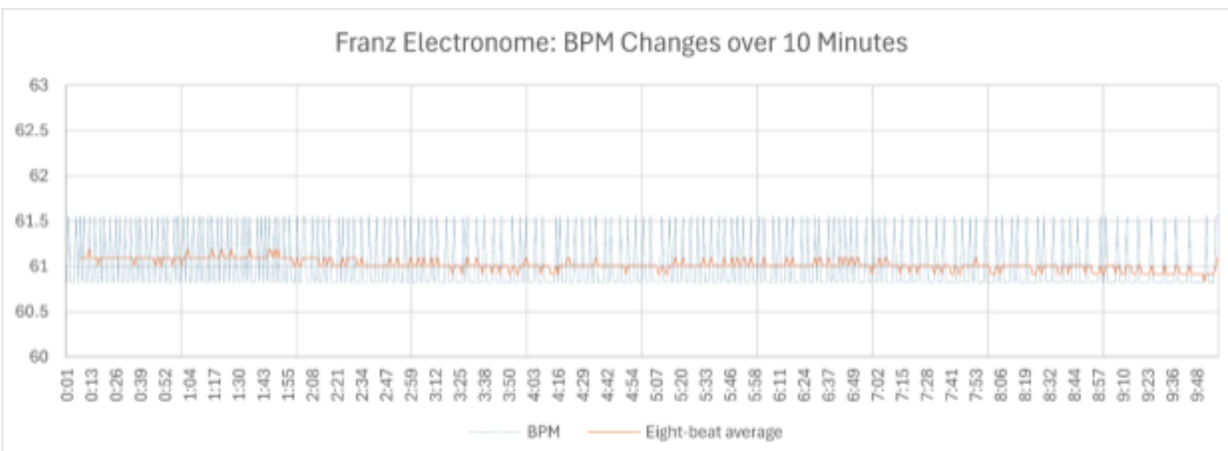

FIGURE 9. Test results, Franz Electronome.

range of only 0.36 BPM over the entire ten minutes, indicating a level of precision at which the performer is extremely unlikely to notice the subtle variations.

Discussion

Though it is possible the thyratron-based metronomes might display yet greater variance given longer sample times, the eight-beat average tempo in the Metronoma sample peaked at the nine-minute mark at 62.11 BPM, only about three percent faster than the eight-beat average at the one-minute mark. These variances are certainly not large enough to render the devices useless to the performer. Broadly speaking, even the Metronoma is sufficiently precise to help the performer toward a reasonably metronomic performance. Yet the variation itself and the unpredictability of its arrival reduce or undermine the metronome's authority. The thyratron devices, aged and to some degree in a state of failure, are not *definitive* sources of pulse in the way that the Korg TM-50 is. The possibility for change and variance is inherent in the thyratron devices, particularly over time scales longer than ten minutes, as might be experienced in a lengthy practice session or most pieces of concert music. As a result, the performer might endeavour to retain a greater sense of internal pulse in order to identify when the metronome's pulse has begun to shift, and to develop a more flexible entrainment to an external source; for instance, recognizing the external source as something which will change over time, rather than representing a rigid and predictable source that can be mindlessly followed. In short, a metronome with perceptible variance (or the threat of variance) cultivates attentiveness, both to one's own pulse and, relatedly, to an external source of pulse which, like a conductor or a chamber music partner, might shift direction at any moment, empowering the individual to choose whether to follow or resist.

But how might these considerations be practically implemented in musicians' practice and pedagogy? The answer certainly does not lie in providing students and professionals with mid-century electromechanical metronomes, which are a bulky and finite resource. Instead, I propose further consideration of the following technological and pedagogical pathways leaping off from the directions inadvertently pointed to by these older devices.

1. Technological Pathways: Though the technological development of the metronome introduced some new problems to Western classical music performance, further technological developments may ameliorate those effects or at least better position the metronome to restore artistic agency.

Digital metronome tools could be developed with a switchable looser interpretation of pulse. These devices or applications might include a "flexibility" mode or similar which could be engaged and disengaged at will, and which could introduce degrees of variance to the pulse. Such a device could vary pulse in a number of different ways. A random number generator could create randomized variations in pulse within a certain range, or there might also be a mode which introduces gradual acceleration and deceleration of tempi in the way the human performers tend to drift progressively over time. Development of these modes would not preclude the use of metronomes as perfectly precise devices when needed, yet could also do much to constructively loosen the metronome's position as authority during practice. Performers practicing with these or other flexibility modes would be encouraged to trust and hone their own sense of pulse as an internally derived phenomenon. In so doing, they might relate with the metronome in a more organic fashion, that is, as a tool aiding their artistry rather than as an authority imposing external strictures upon it.

It could also be possible to develop click tracks reflecting specific recorded performances of a work with which a student might then play along. Such click tracks would necessarily need to respond very sensitively and accurately to recordings. This type of work has already been partially undertaken under the auspices of empirical musicology.[41] Sonic Visualiser has often been employed as an analytical tool for such endeavours, though data generated by the software still requires a certain amount of manipulation to create a click track. The rapid development of artificial-intelligence tools could provide one vector for streamlining the process of harvesting tempo maps from historical recordings. Click tracks generated from historical recordings would still innately bestow authority on the track and the performers who recorded it. However, students could at least avail themselves of experiences that train their rhythmic sensibilities to align more closely with human performance rather than solely with machinelike steadiness and precision.

2. Pedagogical Pathways: The metronome itself is not a limiter on artistic agency. It only becomes such when musicians collectively agree that it is an authority to be followed. A reframing of the metronome's authority among performers would necessarily need to begin at a grassroots level within pedagogy, such that newer generations of musicians develop a more flexible relationship with the metronome as a tool rather than an authority.

For educators teaching Western classical music performance to children and youth, there is a critical opportunity to frame the metronome as a practice aid rather than an arbiter of right or wrong. Young musicians who are encouraged to cultivate a consistent but flexible internal sense of pulse, whether assisted by a metronome or not, will be better positioned to retain agency of their musicianship. Further, these students may gain a more positive relationship with music training based upon their

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[41] See Eric Clarke, "Empirical Methods in the Study of Performance," in *Empirical Musicology: Aims, Methods, Prospects*, ed. Nicholas Cook and Eric Clarke (Oxford University Press, 2004), 77–102; and Danny Zhou and Dorottya Fabian, "Velocity and Virtuosity: An Empirical Investigation of Basic Tempo in Contemporary Performances of Two Large-Scale Works of Chopin and Liszt," *Empirical Musicology Review* 16, no. 2 (2023): 176–204.

own impulses and interests, and may experience a lower incidence of Music Performance Anxiety.

For educators teaching performance to young-adult and early professional music students, concepts such as *rubato* (artistic distortions of tempo) and personal interpretation become increasingly important yet fundamentally at odds with metronomically rigid practicing. It is incumbent upon these educators to encourage continued creativity and artistry around pulse. This is a two-way street: though students must commit to considering pulse as more than a rigid tick from a metronome, those who evaluate their performances must also commit to evaluative practices which do not take metronomic precision as the baseline for success.

CONCLUSIONS

Like the pianoforte or the idiosyncratic standard system of Western music notation, the metronome is here to stay. Initially a response to the needs of a specific moment in time, it has become irreversibly entangled with Western art music as not only an indispensable tool but as something increasingly synonymous with conceptions of pulse and tempo. Yet the history of the metronome is also one of changing uses and purposes: from the earliest applications as a method for communicating tempo through to a means for enforcing tempo and, as in the case of Ligeti's music and others, even through to becoming an instrument in its own right. This flexibility of usage invites current and future musicians to continue devising new relationships with the metronome and to reinvent it in ways which serve new needs.

While the solutions I have proposed here might not be universally accepted, they remain consistent with the metronome's overarching and most original purpose. It is a tool to be used and modified to suit the needs of the moment, rather than an automated authority over a musician's artistry. In this respect, parallels may be drawn with the current discourse over generative AI's nascent "creative" abilities. How much creative agency should be entrusted to technology rather than humans, and how might we govern or understand that technology's outputs? Actions which protect creative authority for human minds and bodies may well prove to be an enticing consideration for our era.

Finally, as a violinist saddled with all the attendant pitch challenges of that instrument, I would be remiss to ignore the other technological elephant in the room: the electronic tuner and smartphone apps which purport to discern on matters of "quality" sound or pitch that is worthy of displaying "Mr. SmileyFace," both of which are features of the popular tuner/metronome app *TonalEnergy*.[42] These areas of technological influence on Western art music practice are newer, less studied, and their effects may only be in the earliest stages. After all, it took many decades for the metronome's influence to reshape our relationship with tempo and pulse, while electronic tuners only began to be somewhat affordable and portable in the late twentieth century (see, for example, the 1975 Korg WT-10). There are still faculty members at prestigious conservatories whose artistic careers were fully established before such tuners were available. Audio analysis software assessing notions like "quality" tone is, needless to say, much newer still. As the influence of these technologies comes to bear on musical performance and practice, the older–and in some ways much simpler–example of the metronome demonstrates the ways in which musical practice can easily yield to the arbitrary authority of tools rather than employ them purely for artistic possibilities. If the strictures of the metronome might be loosened somewhat, or at least examined more frankly and frequently, we may in addition collectively come to develop better models for responding to newer musical practice aid technologies.

[42] TonalEnergy, Inc. *TE Tuner – User Guide (Android)*, accessed August 23, 2024, https://www.tonalenergy.com/tet-user-guide-android.

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