Measuring the Myth: Microtiming and Tempo Variability in the Music of the Rolling Stones

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In this article, we empirically examine microtiming and tempo variability in the drumming of the Rolling Stones' Charlie Watts. We present a new method for microtiming analysis and use it to examine 81 Rolling Stones recordings and 59 songs by other artists. Our study finds that Watts delayed backbeats more consistently than his contemporaries, particularly in releases dating from 1967 to 1973. We also analyze tempo variability in 133 Rolling Stones studio recordings with Watts, finding that tempo variation often reflected song structure and that the band had a general tendency to accelerate in recordings from this same 1967–73 period. After 1973, the music of the Rolling Stones became much steadier, to some extent aligning with trends in mainstream pop. Ultimately, our study provides some evidence for claims commonly made about Watts, but also suggests that much of the discussion may be colored by romanticized notions of authenticity.

Fans often discuss the "feels" of popular music drummers, making claims about the particular features that characterize their sound. The drumming of Charlie Watts of the Rolling Stones has especially been the subject of intense debate. When Watts died in August 2021, a headline in *The Times* of London proclaimed that his drumming "would make drum machines weep" (Hepworth 2021), with the majority of commentators describing his playing as "behind the beat." For example, Bruce Springsteen's drummer Max Weinberg wrote: "Charlie became a proponent—as I am—of a style of rock drumming popularised by the late, great Al Jackson, the famous Stax drummer, where you deliberately play behind the direct backbeat" (Beaumont-Thomas 2021). Others have made a different assessment, with podcast host and drummer Monte Mallin claiming in 2012 that it was Watts being "slightly ahead of the beat" that gave the band its characteristic rhythmic feel.[1] Discussions of Watts's approach to tempo variability have also differed, with some claiming he is "metronomic" while others asserting that the band's tempo ebbed and flowed. Bassist Darryl Jones, who has played with the band for thirty years, said of Watts: "He has a way of being very, very steady without being metronome-like . . . there should be some breathing, you know, and he's great at that" (Ward 2018, 2:29–3:04).

In order to investigate these claims, we engaged in an empirical study focused on microtiming and *tempo variability* in the drumming of Watts with the Rolling Stones. Besides its value for close musical analysis, our study examines value judgments

Online resources for audio examples can be found on the MTSNYS website: https://tnp.mtsnys.org/.

1 MrMonte (Monte Mallin), reply to "Musicians: How Do You Explain Charlie's Technique to Drummers?," *It's Only Rock'n Roll* forum, March 9, 2012, https://iorr.org/talk/read.php?1,1579013,page=1.

connected to popular music: descriptions praising Watts's style of playing as "human," "natural," or "organic" seem informed by an ideology of authenticity, while other drummers or sequencers are described negatively as "mechanical," "lifeless," "cold," or "robotic." Different ways of dealing with rhythm are thus connected to larger philosophies and ways of seeing the world.

In what follows, we first review prior scholarship on microtiming in popular music drumming. We then explain the methodology we developed for analyzing microtiming in the drumming of Charlie Watts. Our third section discusses the results of our microtiming study, revealing the extent to which Watts delayed backbeats in comparison with other drummers. We then turn to tempo variability, identifying common tempo curves in Rolling Stones songs. We present our method of measuring tempo variability with a single number (the coefficient of variation) and apply it to corpora of Rolling Stones songs and songs by other artists, showing trends over time. Finally, we review our findings and discuss how they connect with larger questions of genre and authenticity in popular music.

I. Prior Scholarship on Microtiming in Popular Music Drumming

In 1987, Charles Keil referred to microtiming deviations as "participatory discrepancies" (or "PDs"), which he argued were essential elements of groove in jazz and other popular genres (275, 277). Studies of swing ratios in jazz eventually inspired scholarly interest in microscopically delayed backbeats in rock, with Iyer contending that playing the snare slightly behind the backbeat is a crucial component of African American music and the music it has inspired, contributing to a "relaxed" and "laid back" feel (2002, 406; see also Butterfield 2006, 33, 39–41). Drummers instructed to play in a "laid-back" manner with a click track at a moderate tempo of 96 BPM delayed snare attacks by 17.4 ms on average (Danielsen et al. 2015, 2306; see also similar findings by Câmara et al. 2020, 11).

Other scholarship has attempted to empirically measure listeners' ability to detect such microrhythmic deviations. The just noticeable difference (JND) for timing discrepancies found by Friberg and Sundberg was 2.5 percent of the beat length for tempos between 60 and 200 BPM, meaning that discrepancies of this size or larger were perceptible (1995, 2528). Madison and Merker found that the JND for timing discrepancies was 2.5 percent for listeners with musical training and 4.4 percent for those without (2002, 204). But Madison and Merker have also shown that musicians can subliminally respond to deviations as small as 1.5 ms at tempos between 92 and 100 BPM, even though deviations that small are not consciously recognizable (2004, 71).

Scholars have also sought to determine the extent to which deviations such as playing behind the beat or altering swing ratios contribute to a sense of groove.

Research shows that jazz listeners prefer music with timing discrepancies but also prefer that these discrepancies be relatively small (Hofmann et al. 2017, 339). Similar research suggests that systematic microtiming deviations in jazz are crucial to creating a sense of swing (Nelias et al. 2022, 6–7). Other scholars, however, have been unable to find empirical evidence that microtiming deviations contribute positively to a sense of groove or make the music more pleasurable (Senn et al. 2016, 11; Davies et al. 2012, 507; Madison et al. 2011, 1588). Senn et al., in their review of the extensive literature regarding the effects of microtiming deviations on groove, wrote that research to date had produced surprisingly few insights, though they allowed that exploration of other aspects of microtiming, such as the effect of different *patterns* of microtiming deviation and how microtiming changes over the course of a musical work, could potentially be fruitful (2017, 17–18). Subsequent research by Danielsen et al. (2019) emphasized that parameters like timbre, dynamics, and pitch play an important role in the perception of microtiming, and Senn (2023, 38) recently suggested that a failure to account for these additional parameters may be a reason why previous studies failed to find a relationship between microtiming and groove.

II. Microtiming Methodology Used in This Study

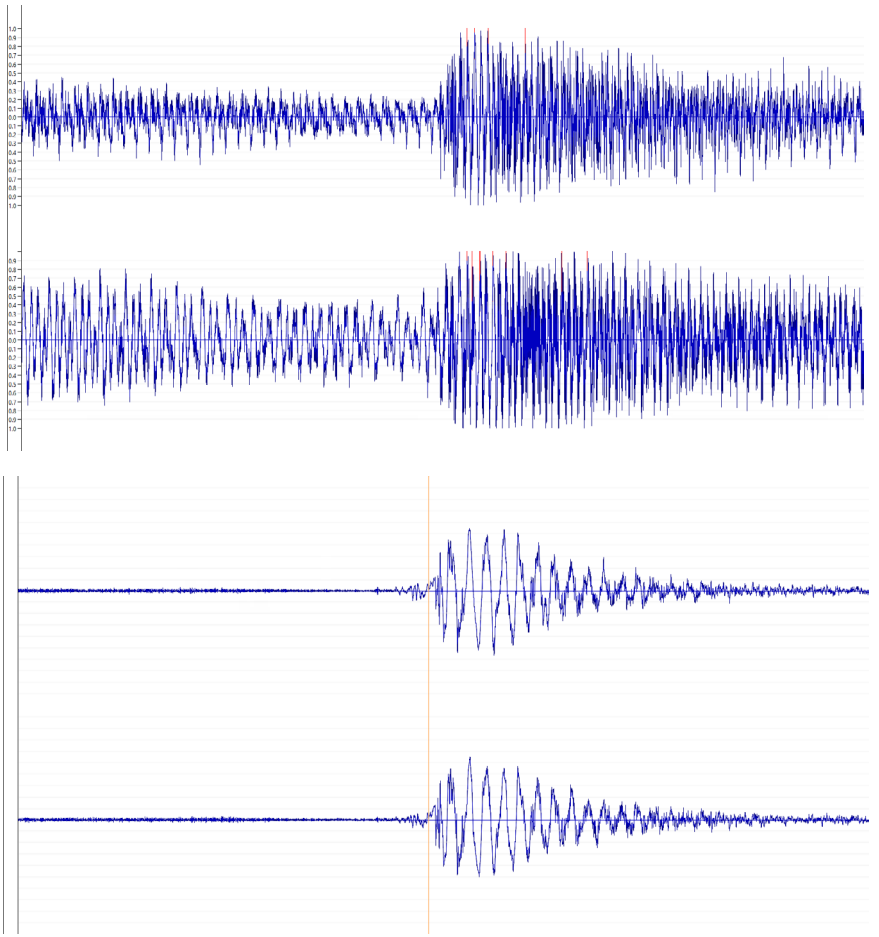
To measure microtiming in Watts's drumming with the Rolling Stones, we used iZotope's RX 9 or the Moises app to first separate the drums from the other instruments and vocals.[2] We then opened the isolated drum audio file in Sonic Visualiser and used the BBC Rhythm: Onsets plugin to automatically mark all quarter-note attacks (Example 1).[3] Using this plugin resulted in markers that did not align with the visual onset of the attack in waveform view but typically appeared immediately after that initial onset. This approach accorded with where we heard the attack as well as with research showing that the perceptual center lies in between the physical onset and the high point of the attack (Danielsen et al. 2019, 403).[4] Using automated attack marker

2 See https://www.izotope.com/ and http://moises.ai. We initially used iZotope RX 9's Music Rebalance tool to isolate the drums, but subsequently found that Moises could do the same job more efficiently, so we switched tools early in the study. Moises, built using a Python library called Spleeter, derives time-frequency masks using machine learning in order to perform source separation (Hennequin et al. 2020; Pang 2019).

3 See https://www.sonicvisualiser.org/ and https://www.vamp-plugins.org/download.html. In the BBC Rhythm: Onsets plugin, we used a Hann window shape, an FFT window size of 128 samples, and a window increment of 32. These settings allowed for a time resolution of 0.7 milliseconds. We started with a threshold setting of 3 and then increased or decreased it to automatically mark the quarter notes. In cases where the algorithm did not detect an attack that actually occurred, we lowered the threshold in a second layer and copied the resulting markers into the first layer. See Baume (2013) for a description of the plugin.

4 Danielsen and others have discussed how there is not always a visual point in the representation of a waveform that will consistently align with human perception of the moment of attack—this is variable between instruments and versions of the same instrument (see also Hellmer and Madison 2015, 150). Identifying the

placement allowed for the replicability of our results and for a more consistent and transparent method than annotating attacks by hand, even as we monitored the plugin's markers to ensure consistency (see footnote 3).



Example 1

Waveform view of "Wild Horses" snare hit prior to drum isolation, including acoustic guitar and bass (top); snare drum after drum isolation and placement of attack markers (bottom).

moment of attack is easier with percussive attacks like drums, yet there is still no single timepoint that can be objectively identified. Identifying the moment of attack can also be complicated when there are near-simultaneous hits on multiple instruments within a drum kit (Hove et al. 2007; see also Câmara 2021, 35–41). The separation software we used did not allow for automatic separation of the hi-hats from the snare and kick; in the occasional instances when the onset detection plugin created two markers for a single beat, we analyzed only the broader-spectrum snare attack.

We focused entirely on quarter notes, in part to simplify a potentially overwhelming task, but also because of Watts's drumming style and the nature of the discussion around it: the standard backbeat pattern—with kick drum on beats 1 and 3, snare on beats 2 and 4, and hi-hat on the eighth notes—was the primary pattern for Watts (as well as for rock music more generally).[5] Our microtiming analysis therefore focused on passages either with the standard rock backbeat or a variant.[6] Once we had markers for all relevant attacks, we exported the data to an Excel template that would automatically calculate measurements such as the length and tempo of each bar and the amount of anticipation or delay of each attack.

In order to measure whether quarter-note attacks were occurring before or after the beat, it was necessary to identify the locations of these beats in a context in which tempo "drift" was constant (Räsänen et al. 2015, 2). Slight changes of tempo inevitably occur even when a drummer attempts to play steadily. Without a click track (or similar reference), there is no fixed pulse that can be authoritatively identified as the "true pulse."[7] Scientists do not know how many prior attacks the brain accounts for when predicting the timing of subsequent beats.[8] We therefore incorporated a variety of approaches in our research. Prior analysts have sometimes used the current bar as the basis for identifying beats (tempo induction) when the tempo is not steady (see Frane 2017, 296; Freeman and Lacey 2002, 549; and Troes 2017, 35). While this approach evaluates the placement of drum attacks in part on the basis of attacks the listener has not yet heard, listeners to a large extent hear and evaluate music retrospectively (Huron 2006, 13–15), so that they may have an impression of an attack having been delayed only after having heard the bar or even part of the bar in question. Example 2 illustrates our implementation of this approach, calculating the average duration of a beat within the current bar (based on quarter-note attacks marked in Sonic Visualiser) and then comparing the individual measured beat lengths with this average.

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5 Eighth notes on the hi-hat are a fundamental component of the standard rock backbeat pattern, but comments on Watts's drumming have tended to focus on the presence or absence of delay or anticipation of the backbeats and the kick drum rather than the hi-hat eighths. Additionally, Watts typically did not play the hi-hat on beats two and four (see footnote 19, below). Given that some blues-influenced Rolling Stones songs employed swing, potential future research could examine Watts's use of swung eighths on the hi-hat or ride cymbal.

6 We input data from all quarter-note attacks, even if there was a brief departure from the usual pattern of kick on beats 1 and 3 and snare on beats 2 and 4. For instance, if there was a bar in which the snare or hi-hat, but not the kick, played on beat 1, we would still encode that beat. If no attack occurred on a beat, we did not insert a marker; there would just be a gap in our table. We avoided analyzing songs or parts of songs without a fairly steady stream of quarter-note attacks, so there were rarely a large number of gaps in the passages we analyzed.

7 For this reason, many microtiming studies, such as Kilchenmann and Senn (2015), have drummers record to a click track when creating recordings for analysis.

8 More recent musical stimuli have a greater effect on listener expectations than ones further in the past, but scientific estimates differ as to how quickly listeners disregard earlier information (Bailes et al. 2013, 1).

1) Identify each interonset interval in the current bar:

Beats 1-2: 811 ms
Beats 2-3: 758 ms
Beats 3-4: 836 ms
Beats 4-1: 727 ms

2) Determine total length of current bar by subtracting the timepoint of the downbeat of the current bar from the timepoint of the downbeat of the next bar:

DownbeatN - DownbeatC = Bar Duration

176,036 ms - 172,904 ms = 3,132 ms

3) Divide length of current bar by 4:

Bar Duration / 4 = Mean Duration

3,132 ms / 4 = 783 ms

4) Compare interonset intervals with average length of a beat in the bar:

Beat - Mean Duration = Deviation

811 ms - 783 ms = 28 ms
758 ms - 783 ms = -25 ms
836 ms - 783 ms = 53 ms
727 ms - 783 ms = -56 ms

Example 2
Calculation of deviation from average beat length in the current bar (analyzing "Wild Horses," 5:24–5:27); values rounded for demonstration.

An alternative approach examines what was heard *immediately prior* to the attacks in question, with these previous attacks creating an expectation for kick and snare placement in the following bar. This method is similar to secondary approaches used by Butterfield (2006, 50–51) and Frane (2017, 296).[9] In implementing this approach, we used the entire bar immediately preceding the bar in question as the basis for calculating beat placement expectation. As seen in Example 3, we compared the interonset intervals (IOI) in the current bar with the average beat length from the previous bar, calculating that average beat length entirely on the basis of the time between successive downbeats.[10] This provided a positive or negative number indicating whether

9 Butterfield evaluates timing based both on the current measure and on the previous measure. Frane, as a secondary method of measurement, uses only the previous *beat* as the basis for determining listener expectation. Hellmer and Madison also use previous attacks to predict future ones but rely on the BeatRoot beat tracking system (2015, 152, 154). The BeatRoot system does not examine a fixed past time when making beat predictions, but instead creates initial tempo hypotheses and then reacts to subsequent onset information to adjust the hypotheses (Dixon 2001; Dixon 2007). BeatRoot, however, problematically sometimes snaps beats to actual onsets and often generates beat tracking errors.

10 If there was no attack on a downbeat, then that bar could not be used as the basis for a "prior bar" calculation, and the subsequent bar would be excluded from analysis.

the attack is ahead of or behind its expected location based on the tempo established in the prior bar. The difference between using the current bar and using the previous bar as the basis for expectation turns out to be relatively small in most cases, though the previous-bar method is more sensitive to significant tempo drift: in particular, if the tempo is accelerating, then the previous-bar method will register slightly less delay than the current-bar method.

1) Identify each interonset interval in the current bar:

Beats 1-2: 811 ms
Beats 2-3: 758 ms
Beats 3-4: 836 ms
Beats 4-1: 727 ms

2) Determine total length of prior bar by subtracting the timepoint of the downbeat of the previous bar from the timepoint of the downbeat of the current bar:

DownbeatC - DownbeatP = Bar Duration

172,905 ms - 169,698 ms = 3,207 ms

3) Divide length of prior bar by 4:

Bar Duration / 4 = Mean Duration

3,207 ms / 4 = 802 ms

4) Compare interonset intervals in current bar with average length of a beat in the prior bar:

Beat (current bar) – Mean Duration (prior bar) = Deviation

811 ms - 802 ms = 9 ms
758 ms - 802 ms = -44 ms
836 ms - 802 ms = 34 ms
727 ms - 802 ms = -75 ms

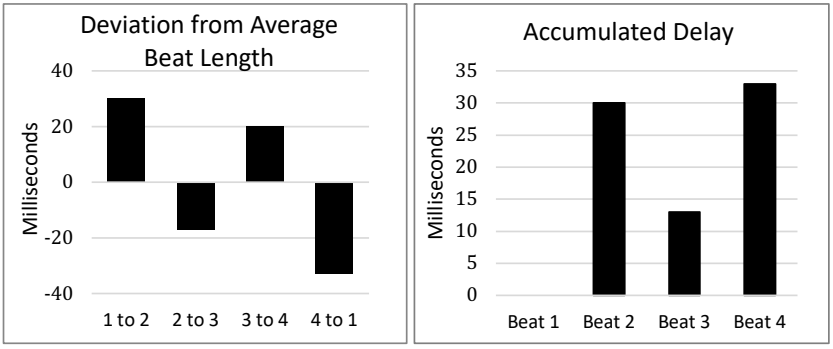
Example 3
Calculation of deviation from average beat length in the previous bar (analyzing "Wild Horses," 5:24–5:27); values rounded for demonstration.

It is important to consider attacks not only in relation to the nearest beat but also in relation to the downbeat of each bar. Doing so is consistent with the importance that listeners assign to downbeats (Butterfield 2007, 8–9) as well as with the practices of drummers who keep the downbeats relatively steady but delay or accelerate within the bar.[11] Keeping the downbeats steady while playing delayed backbeats requires that the IOI between beats 2 and 3 and between beats 4 and 1 be *smaller* than average.[12]

11 When asked about playing behind the beat, renowned session drummer John Robinson said that he would keep the bass drum exactly on time but adjust the other attacks around it (Miller 1994, 21–22).

12 The asymmetric placement of quarter-note attacks within a relatively steady tempo can be compared to swung eighth notes, where the *beat* is steady but there is an unequal division of the beat. As Iyer points out, the

But as seen with beat 3 in Example 4, beat 3 or beat 4 can be heard as late in relation to the downbeat even if the IOI preceding it has a below-average duration. We therefore calculated not only deviation from IOIs but also accumulated delay. Considering the possible approaches of using either the previous or current bar as the basis for beat calculation as well as employing either accumulated delay or individual onsets, we used four calculation methods for each song: accumulated-current, accumulated-previous, IOI-current, and IOI-previous (Example 5).



Example 4

Accumulated delay in relation to the downbeat (analyzing a bar from "Wild Horses," 5:14–5:18). Assuming a constant tempo and delayed backbeats, interonset intervals from 2 to 3 and 4 to 1 must be negative (left); because beat 2 is delayed more than beat 3 is early, beat 3 may also be perceived as late (right).

In order to account for listener expectation and the importance of downbeats, we rely on the accumulated-previous approach (using the prior measure to calculate beat expectation and measuring attacks in relation to their distance from the downbeat) as our primary method here. While the other three methods can also provide valuable insights, we rely on one method for simplicity, clarity, and to allow for consistent comparisons between songs.[13] Our discussion below primarily focuses on the application of this

timing of the kick and that of the snare are interrelated, such that referring to a microtiming deviation as a late snare or as an early kick "is a matter of perspective" (2002, 407). Relatedly, Danielsen discusses how downbeats are expected to be played slightly early in soul and other genres (2006, Chapter 5). Still, the fact that asymmetric division of the bar is more often described as a "delayed backbeat" than an "early downbeat" reflects how the downbeat serves as a point of reference for most listeners.

13 Our focus on the drums does not encompass the contributions to rhythmic feel of the other members of the band. Watts was just one part of the band and reacted to the playing of the other musicians. Individual band members can have contrasting microrhythmic feels (Benadon 2006, 82), and it has been theorized that microrhythmic discrepancies between the drums and bass are crucial to groove in jazz (Butterfield 2010, 157–158). We focused on drums in this project for the sake of simplicity and because the precise timing of drum attacks can more reliably be specified than that of bass or guitar attacks.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
								Accumulated, rel. to CURRENT bar average			Accumulated, rel. to PREVIOUS bar average				IOI deviation, CURRENT bar average				IOI deviation, PREVIOUS bar average			
2	Bar	Attack time	Tempo prev. bar	Length of previous bar	IOI beat 1 to 2	IOI beat 1 to 3	IOI beat 1 to 4	Beat 2 (ms)	Beat 3	Beat 4	Beat 1	Beat 2	Beat 3	Beat 4	1 to 2	2 to 3	3 to 4	4 to 1	1 to 2	2 to 3	3 to 4	4 to 1
3	MEAN		73	3.292	0.852	1.661	2.502	30	16	30	-13	27	8	23	30	-14	16	-30	27	-19	15	-31
4	STDEV		2.2	0.099	0.033	0.061	0.076	20	19	15	57	27	36	42	20	19	21	15	27	19	21	23
5	1	1.142																				
6		2.035			0.893			-1							-1							
7		2.954				1.811			23							25						
8		3.833					2.691			9							-15					
9	2	4.718	67.1	3.576														-9				
10		5.620			0.902			38				8			38				8			
11		6.480				1.762			34				-26			-4				-34		
12		7.351					2.633			42				-49			7				-23	
13	3	8.173	69.4	3.455							-121							-42				-72
14		9.063			0.890			38				27			38				27			
15		9.929				1.756			51				29			13				2		
16		10.785					2.612			54				21			4				-7	
17	4	11.583	70.3	3.410							-44							-54				-65
18		12.486			0.903			41				50			41				50			
19		13.315				1.731			8				26			-33				-24		
20		14.199					2.615			30				57			22				31	
21	5	15.031	69.6	3.447							37							-30				-20

Example 5

Microtiming calculations for “Wild Horses,” starting from 1:17 (listed “attack times” are numbered from this point).

method to analysis of beat 2, in part because Watts and other artists showed similar tendencies with regard to beats 2 and 4,[14] but also because using the accumulated decay approach results in the same values for beat 2 as using IOIs.

We employed multiple approaches to measuring the significance and potential perceptibility of deviations from expectation. The positive or negative measurements in milliseconds (indicating whether an attack was relatively late or early) were compared with a hypothesized zero deviation via a two-sided one-sample *t*-test, providing a *p*-value that indicates whether the mean deviation was statistically significant. We also calculated the percentage of second and fourth beats in each song that were delayed by the 2.5 percent of mean IOI standard of conscious perceptibility (discussed above; hereafter referred to as "the 2.5 percent of mean IOI threshold" or "substantial" delay). While the perception of microtiming deviation likely depends not only on the measurable timing but also on factors such as timbre, duration, amplitude, the listener's musical training, and the activity of the other instruments in the texture (Danielsen et al. 2019; Frane and Shams 2017; Butterfield 2007, 19), 2.5 percent of mean IOI can be thought of as the lower end of possible conscious recognition by a musically trained listener. We have thus used this threshold as a benchmark in our statistical evaluations.[15]

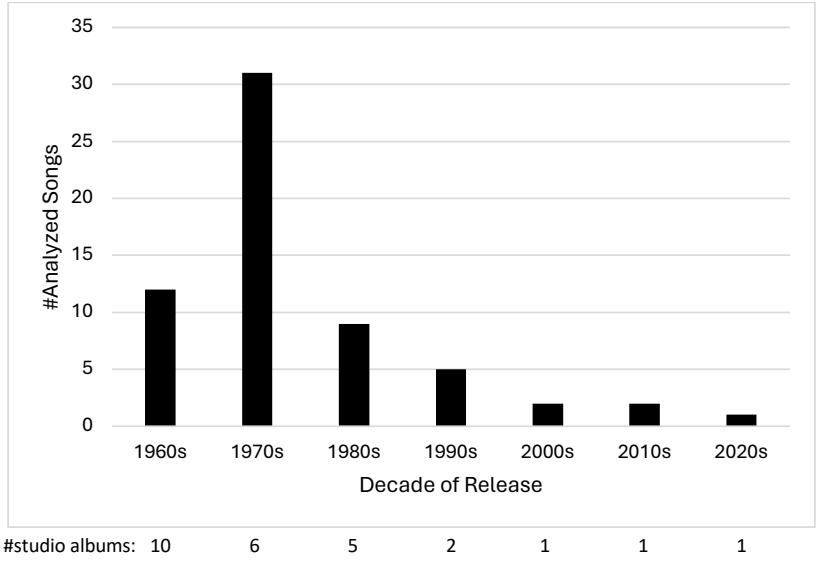
We analyzed 62 Rolling Stones studio recordings with Watts on drums for microtiming (Appendix Example 1), 19 Stones live recordings (see Example 15, below), and 59 recordings by other artists contemporary with the Stones (including three Stones tracks with a different drummer; Appendix Example 2), focusing on songs containing passages with a rock backbeat pattern or variant.[16] The 19 Stones live recordings we analyzed include selections from each of the first six decades of the band's career and represent a variety of tempos (Example 6). We analyzed a relatively small number of songs from the 1960s (even though the Stones released a large number of studio recordings during that decade) because the inferior recording technology of the era often makes it difficult to accurately identify the placement of kick drum attacks. Example 7 shows the breakdown by decade of analyzed songs by other artists, which predominantly use the standard rock backbeat or a variant. These songs were selected

14 There was a fairly strong correlation between the mean beat 2 and mean beat 4 deviations in a song; see footnote 17 below.

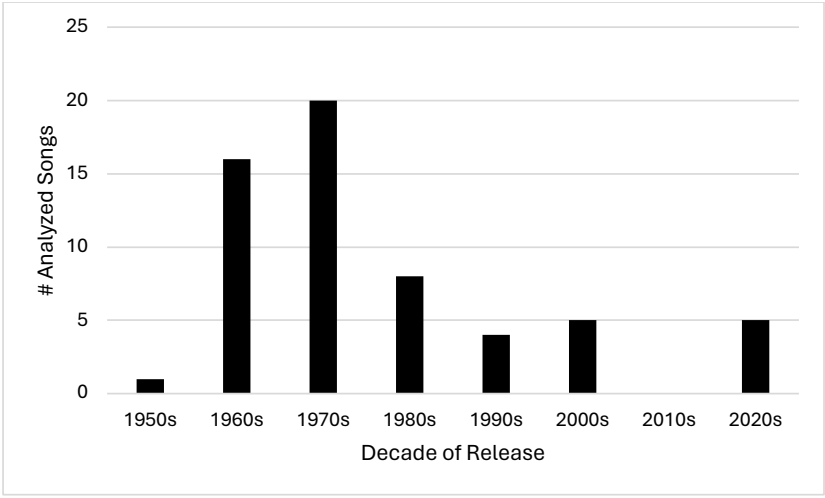
15 Madison and Merker's finding (2004, 71) that musicians can react to deviations from isochrony as small as 1.5 milliseconds suggests that discrepancies smaller than 2.5 percent of IOI could change the "feel" of a Stones recording for a listener even if they would not be able to consciously recognize such small deviations.

16 In most instances, the microtiming analysis we did for a given song is of a subset of the song's entire length. This was in large part to focus on passages where there is a standard rock backbeat pattern or variant and where there were not too many fills or syncopations that would interfere with marking quarter-note attacks. This approach prioritized obtaining samples of more songs over doing analyses of a smaller number of full songs.

to serve as rough chronological and stylistic analogs of the Stones songs we analyzed or because they sounded like they might have particularly delayed or early backbeats.



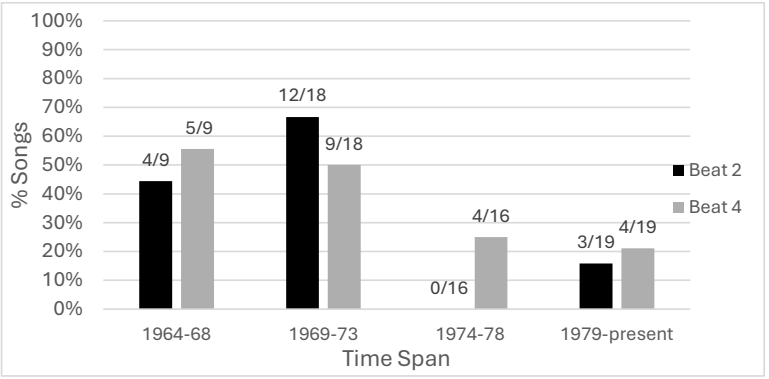
Example 6
Distribution by decade of the 62 Rolling Stones studio recordings analyzed for microtiming, including the total number of studio albums the band released in each decade (excluding albums prior to 1968 that were duplicates created for an alternate market).



Example 7
Distribution by decade of the 59 recordings by other artists analyzed for microtiming.

III. Microtiming Study Results

Our analysis of microtiming examines delayed backbeats in the drumming of Watts and how his approach compares with his contemporaries. Our results reveal that microtiming deviations in Watts's drumming varied over the course of his career. As shown in Example 8, of the 19 Stones studio recordings with the highest percentage of substantially delayed beat 2 attacks, 12 were released between 1969 and 1973. When the period is expanded by two years to 1967–73, it accounts for 15 of the 19 (Example 9; Appendix Example 1 shows the results for all analyzed songs). Example 10 compares the data for Watts for 1967–73 with that for the rest of his career, showing how he substantially delayed a much greater percentage of his beat 2 attacks in this period (45.5 percent) than in the rest of his career (20.6 percent). Watts also substantially delayed beat 4 attacks more in the 1967–73 period (39.4 percent) than in the remainder of his time in the band (32.2 percent).[17]



Example 8

Percentage of Rolling Stones songs by era that have at least 40 percent of their backbeat attacks delayed at least 2.5 percent of mean IOI. The ratio above each bar indicates the number of songs meeting this standard versus the total number of songs analyzed from that era.

After 1973, however, examples of consistent backbeat delay in Watts's drumming are rare. We found only three Stones studio recordings released after 1973 (out of 35 analyzed from this period) that substantially delay at least 40 percent of their beat

17 Considering the entirety of Watts's career, there was a fairly strong correlation between the average amount of delay of beat 2 in songs and that of beat 4, with $r = .81$ for the 62 Watts studio recordings. The recordings with the most consistent beat 2 delays, however, were not always those with the most consistent beat 4 delays. "Monkey Man" and "Sister Morphine," for instance, showed strong tendencies towards beat 2 delay but not for beat 4, while the reverse was true of "All Down the Line." There was a similar correlation between delay of beat 2 and beat 4 in the 59 analyzed recordings with other drummers, with $r = .84$.

Song Title	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)								Portion Analyzed	*n*
			Bt. 2 JND Early %	**Bt. 2 JND Late %**	Bt. 4 JND Early %	Bt. 4 JND Late %	Bt. 1 *M*	Bt. 2 *M*	Bt. 2 *SD*	Bt. 2 *p*	Bt. 2 % of IOI	Bt. 3 *M*	Bt. 4 *M*	Bt. 4% of IOI		
Monkey Man	1969	103	0	**87**	19	35	-4	28	13	<0.001	4.7	5	9	1.8	0:21-4:00	93
2000 Light Years from Home	1967	123	7	**73**	16	62	-3	23	19	<0.001	4.8	0	18	3.7	0:54-2:45	55
Wild Horses	1971	73	7	**64**	16	50	-13	27	27	<0.001	3.3	8	23	2.6	full song	45
Sister Morphine	1971	94	3	**56**	24	38	-4	20	20	<0.001	3.1	9	9	1.5	2:37-5:00	39
Let It Bleed	1969	114	3	**55**	18	40	-2	14	16	<0.001	2.7	1	8	1.6	0:08-2:17	58
One More Shot	2012	123	2	**55**	8	56	0	16	16	<0.001	3.4	7	19	3.9	0:08-1:46	51
Salt of the Earth	1968	94	16	**53**	30	40	5	20	37	0.02	3.5	21	25	3.9	1:21-2:16	19
Ventilator Blues	1972	67	0	**51**	11	28	-2	23	16	<0.001	2.6	6	18	1.3	full song	47
I'm a King Bee	1964	105	0	**50**	6	51	-1	14	10	<0.001	2.4	0	14	2.5	full song	64
Jigsaw Puzzle	1968	107	5	**49**	28	41	-4	15	21	<0.001	2.8	6	8	1.5	0:54-2:45	61
Oh No Not You Again	2005	141	3	**49**	16	51	0	10	9	<0.001	2.4	3	8	2.0	0:01-1:08	37
Gimme Shelter	1969	117	0	**48**	15	41	-1	13	14	<0.001	2.5	0	8	1.5	0:41-2:00	40
Rocks Off	1972	142	0	**48**	6	51	0	13	12	<0.001	3.0	0	15	3.5	0:00-2:03	71
Tumbling Dice	1972	111	4	**46**	17	48	-2	12	15	<0.001	2.2	7	14	2.7	0:02-2:21	57
Let It Loose	1972	78	5	**45**	18	47	-7	21	27	<0.001	2.6	8	17	2.2	0:00-3:14	42
Angie	1973	70	14	**45**	15	46	-4	16	31	<0.001	1.9	11	12	1.5	0:47-4:25	62
Loving Cup	1972	78	0	**44**	18	45	-3	19	13	<0.001	2.5	6	14	1.8	0:54-1:44, 2:24-3:00, 3:11-3:40	34
Already Over Me	1997	75	2	**42**	25	39	-3	15	17	<0.001	1.9	0	4	0.5	0:40-3:45	57
Torn and Frayed	1972	89	0	**41**	17	23	-5	15	15	<0.001	2.2	7	6	0.8	0:06-1:30	29
Mean (all 62 studio recordings)	1979	108	10	29	23	35	-3	7	16		1.1	3	6	1.0		44
Standard Deviation	13	27	11	19	9	11	4	9	6		1.5	5	7	1.3		26
Median	1975	111	7	26	21	32	-2	6	15		0.9	1	5	0.8		37
Minimum	1964	40	0	0	6	19	-20	-15	9	<0.001	-2.5	-17	-10	-2		13
Maximum	2020	169	51	87	46	62	6	28	37	0.996	4.8	21	25	3.9		152

Example 9

The 19 Rolling Stones studio recordings with the greatest percentage of beat 2 attacks delayed at least 2.5 percent of mean IOI ("Bt. 2 JND Late %"). The "Bt. 2 % of IOI" translates the raw beat 2 mean delay number into a percentage of the mean IOI for the song. The *p*-values for beat 2 deviation means are the result of two-sided one-sample *t*-tests with a null hypothesis of a mean of zero; "*n*" indicates the number of beat two attacks analyzed in the song.

Time Frame	#Songs	Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)							#m.
			Bt. 2 JND Early %	Bt. 2 JND Late %	Bt. 4 JND Early %	Bt. 4 JND Late %	Bt. 1 *M*	Bt. 2 *M*	Bt. 2 *SD*	Bt. 2 % of IOI	Bt. 3 *M*	Bt. 4 *M*	Bt. 4 % of IOI	
1967-1973	22	98.8	4.9	45.5	19.0	39.4	-3.2	14.9	18.9	2.4	4.7	10.8	1.7	52.2
Not 1967-1973	41	112.3	13.3	20.6	24.8	32.2	-2.2	2.8	14.2	0.4	1.4	3.2	0.6	40.2

Example 10

Comparison of the microtiming means for analyzed Rolling Stones songs in the 1967–73 period with those outside of this period. "Bt. 2 % of IOI" and "Bt. 4 % of IOI" translate the mean beat 2 deviation into a percentage of mean beat length; "#m." indicates the mean number of measures analyzed in the songs. Comparing the data in these two time periods, $p < .001$ for both Bt. 2 JND Late % and for Bt. 2 % of IOI.

2 attacks: the ballad "Already Over Me," the up-tempo "Oh No Not You Again," and "One More Shot" (Example 9).[18] "Oh No Not You Again" and "One More Shot" also substantially delay at least 40 percent of their beat 4 attacks. An additional six recordings dating after 1973 (two of them from 1974) delay at least 40 percent of their beat 4 attacks more than the 2.5 percent of mean IOI threshold, but the percentage of songs meeting this standard for beat 4 is similarly much lower after 1973 than before (Example 8). And while there are patterns of consistent delay in numerous Stones recordings, our evidence suggests that even during the 1967–73 time period (in which the most delayed backbeats were found), some songs—such as "I Got the Blues," "Casino Boogie," and "Sweet Virginia"—lacked consistent backbeat delay.[19] Even in the songs that show the most consistent delay, there is a great deal of variability from attack to attack, with the standard deviations for the placement of beat 2 in the songs in Example 9 primarily ranging between 10 and 20 ms. Thus, while a tendency towards delay is clear in numerous songs between 1967 and 1973, there appears to be a significant element of randomness as far as the exact *amount* of delay.

Another measure of the amount of beat 2 delay in a song is the mean deviation from expectation, expressed as a percentage of the mean beat length for the song. A review of the songs with beat 2 mean percentage delays of at least 2.5 percent of IOI

18 In his 2012 review of "One More Shot," Neil McCormick wrote that Watts's "swinging beat [was] just that micro-fraction behind where you might expect it to be."

19 Stones guitarist Keith Richards has linked the practice of delaying the backbeat to Watts's idiosyncratic habit of not playing the hi-hat when he hits the snare (Richards 2010, 121). Despite Richards's claim, there is little evidence that Watts's habit of not hitting the hi-hat on beats 2 and 4 caused him to play behind the beat. The fact that Watts did not always play behind the beat when using the technique calls into question Richards's contention. Video of the Stones playing "I Got the Blues" (The Rolling Stones 2022), for instance, clearly shows Watts using this technique, but analysis of this performance reveals that he played the backbeats consistently *early*. Also undermining Richards's theory is the fact that the snare is at times delayed when Watts uses the ride cymbal instead of the hi-hats for eighth-note subdivisions, as in the studio recordings of "Angie" (1:43–1:56) and "No Use in Crying" (0:40–1:00); Watts typically played all eighth-note subdivisions when playing the ride.

Song Title	Year	Mean Tempo	Accumulated Deviation, Relative to Previous (Means in ms)								Portion Analyzed	*n*
			Bt. 1 *M*	Bt. 2 *M*	Bt. 2 *SD*	Bt. 2 *p*	**Bt. 2 % of IOI**	Bt. 3 *M*	Bt. 4 *M*	Bt. 4 % of IOI		
2000 Light Years from Home	1967	123	-3	23	19	<0.001	**4.8**	0	18	3.7	0:54-2:45	55
Monkey Man	1969	103	-4	28	13	<0.001	**4.7**	5	9	1.8	0:21-4:00	93
Salt of the Earth	1968	94	5	20	37	0.03	**3.5**	21	25	3.9	1:21-2:16	19
One More Shot	2012	123	0	16	16	<0.001	**3.4**	7	19	3.9	0:08-1:46	51
Wild Horses	1971	73	-13	27	27	<0.001	**3.3**	8	23	2.6	full song	45
Sister Morphine	1971	94	-4	20	20	<0.001	**3.1**	9	9	1.5	2:37-5:00	39
Rocks Off	1972	142	0	13	12	<0.001	**3.0**	0	15	3.5	0:00-2:03	71
Jigsaw Puzzle	1968	107	-4	15	21	<0.001	**2.8**	6	8	1.5	0:54-2:45	61
Let It Bleed	1969	114	-2	14	16	<0.001	**2.7**	1	8	1.6	0:08-2:17	58
Ventilator Blues	1972	67	-2	23	16	<0.001	**2.6**	6	18	1.3	full song	47
Let It Loose	1972	78	-7	21	27	<0.001	**2.6**	8	17	2.2	0:00-3:14	42
Gimme Shelter	1969	117	-1	13	14	<0.001	**2.5**	0	8	1.5	0:41-2:00	40
Loving Cup	1972	78	-3	19	13	<0.001	**2.5**	6	14	1.8	0:54-1:44, 2:24-3:00, 3:11-3:40	34

Example 11

The 13 analyzed Rolling Stones studio recordings with a mean beat 2 delay of at least 2.5 percent of the average beat length (accumulated delay; expected attacks determined by tempo of previous bar), ordered by highest percentage of beat 2 attacks that are delayed at least 2.5 percent of mean IOI; "*n*" indicates the number of beat 2 locations analyzed. "Bt. 2 % of IOI" translates the raw beat 2 delay into a percentage of the mean beat length. "Bt. 2 *p*" compares the mean beat 2 delay with 0.

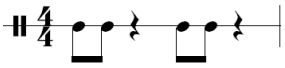
(Example 11) similarly shows that the most extreme songs in this regard generally came from the 1967–73 period. Of the 13 songs in Example 11 that meet this standard, all except for "One More Shot" date between 1967 and 1973. The mean percentage delay of beat 2 in the 1967–73 period was 2.4 percent, while outside of that period it was only 0.4 percent; beat 4 delays were also higher in the 1967–73 period (1.7 percent versus 0.6), as seen in Example 10. The mean amounts of delay seen in Example 11 (measured in milliseconds) are for the most part similar to or greater than the mean snare delays of 17 ms by the drummers studied in Câmara et al. (2020, 11) and Danielsen et al. (2015, 2306) who were instructed to play in a "laid-back" manner.[20] Five tracks, four of them released between 1967 and 1971, rank particularly high on both the most consistent delay and greatest percentage delay lists: "2000 Light Years from Home," "Monkey Man," "Wild Horses," "Sister Morphine," and "One More Shot." Of these, "2000 Light Years from Home," "Wild Horses," and "One More Shot" also have a strong tendency towards beat 4 delay. While the rootsy, laid-back feel and relatively slow tempos of "Wild Horses" and "Sister Morphine" are consistent with the typical musical associations of delayed backbeats discussed above in section I, "2000 Light Years from Home," with its fast tempo and provocative sci-fi soundworld, and "Monkey Man," with its sophisticated-sounding extended tertian harmonies and polished production, clash with these associations. Both "2000 Light Years" and "Monkey Man," however, have relatively active, syncopated kick patterns (Example 12), an approach associated in our study with backbeat delay and its complement, an early kick drum.[21]

In "Monkey Man" (1969), beat 2 delay varies between 10 and 80 ms, but the second beat is always late, as seen in Example 13.[22] There is also a tendency towards beat 4 delay (mean of 9 ms) in "Monkey Man," though this tendency is much less pronounced than it is for beat 2 (with a mean delay of 28 ms). The delayed backbeats in the song reflect the narrator's "lazy" lifestyle, in which he "always has an unmade bed," is compared to "broken eggs" and "cold pizza," and "loves to play the blues." Looking at the beat 2 microtiming graph in more detail, we see that while all the beat 2 attacks are late, there is generally alternation between high and low delay values rather than

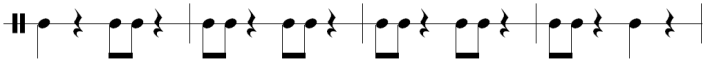
20 The mean standard deviations in these studies ranged between 11 and 19 ms, with smaller standard deviations at faster tempos. The standard deviations in Watts's playing shown in Example 11 tend to be somewhat greater, which is unsurprising given that Watts was not playing with a click track (see section V, below), while the drummers in the Câmara et al. and Danielsen et al. studies were playing with either a metronome or a tempo invariant backing track.

21 The syncopated kick patterns in "Sister Morphine" and "One More Shot" provide additional examples. While syncopated kick patterns tended to be associated with backbeat delay in our study, songs with simple, unsyncopated kick patterns tended towards early backbeats; see our discussion of early backbeats, below.

22 This is despite the overall pattern of acceleration in the song (see section IV, below).



"2000 Light Years from Home"



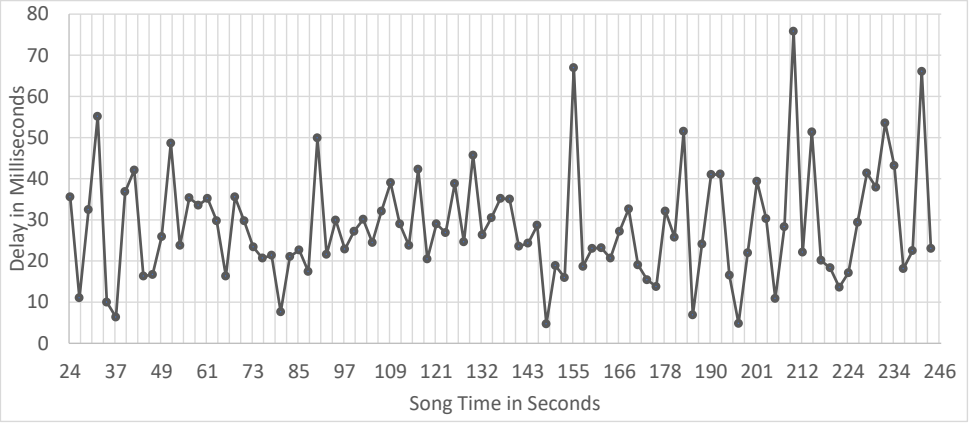
"Monkey Man"

Example 12
Primary kick drum patterns in "2000 Light Years from Home" and "Monkey Man."

a clustering of one or the other. There are only a few spots in "Monkey Man" where there are four or five consecutive beat 2 attacks with similar amounts of delay, most notably at 0:56–1:03 (delays between 30 and 35 ms), at 1:32–1:46 (seven consecutive delays between 22 and 32 ms), and at 2:36–2:43 (delays between 19 and 23 ms). Two of these three relatively consistent areas occur at formally analogous points: 0:56–1:03 is the second half of the first verse, where the harmony shifts to ♭VI and the refrain occurs, while 1:32–1:46 roughly aligns with the second half of the second verse, with the same harmonic change and the refrain. This formal echo recalls both Iyer's claim that microtiming deviations "convey information about musical structure" (2002, 397) and Hellmer and Madison's supposition that microtiming patterns can correspond with particular section types (2015, 158). Other than this correspondence, however, there is no clear pattern in beat 2 delay lengths over the course of the song; instead, just a slight trend towards greater delay in the second half of the recording, with six of the seven largest delays occurring there.[23] Fittingly, the portion of the song with the most extreme levels of backbeat delay, both early and late, is the chaotic outro, with cymbal crashes, drum fills, and Mick Jagger's vocal improvisations.

Like "Monkey Man," the 1972 Stones album *Exile on Main Street* contains some of the clearest and most consistent examples of delayed backbeats. The album was produced by drummer Jimmy Miller, whose time working with the band (1968–73) appears particularly correlated with delayed backbeats and tempo variability (see sections IV and V, below). "Ventilator Blues," "Rocks Off," "Tumbling Dice," "Let It Loose," "Loving Cup," and "Torn and Frayed" each contain relatively consistent

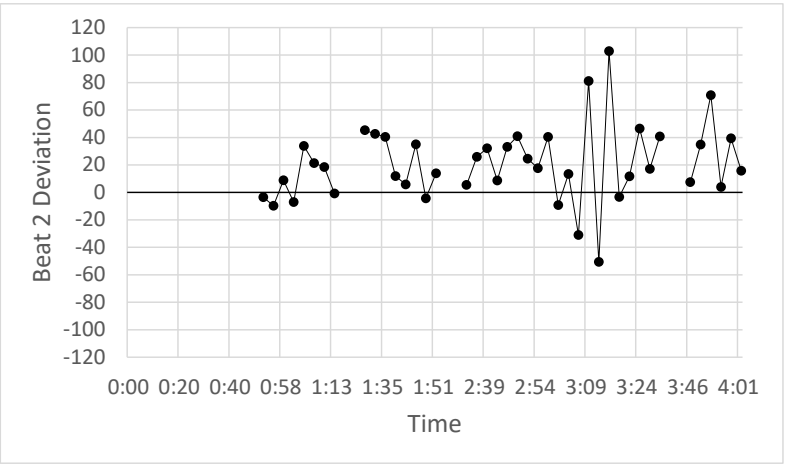
23 Butterfield writes that "competent" drummers tend to "fairly consistently" place their attacks either on top of or behind the beat (2006, 36). Looking at the microtiming of "Monkey Man" and other songs in detail suggests that, while consistent placement behind or ahead of the beat is possible for a drummer playing without mechanical assistance, the *amount* of displacement may be highly variable even with an expert drummer.



Example 13
Deviation in "Monkey Man" of beat 2 from expected position based on average beat length in the previous bar (audio example, 0:50–1:50).

and substantial backbeat delays, though other tracks from the album, such as "Casino Boogie" and "Sweet Virginia," lack such a tendency. The gospel-inflected "Let It Loose" from this album provides an example of a strong tendency to delay the snare on beats 2 and 4 (Example 14). In this song, the average delay of the attack on beat 2 in comparison with the expectation created by the previous bar is 21 ms, and the average accumulated delay for beat 4 is 17 ms. Of the 42 beat 2 attacks, 19 (45 percent) are delayed by at least 2.5 percent of mean IOI, and 32 (76 percent) of the beat 2 attacks are delayed by at least 5 ms. By comparison, only two of the 42 beat 2 attacks are 2.5 percent of the average IOI early. The substantial delays to beats 2 and 4 are mostly consistent, with the exception of a passage at 3:03–3:21 that has a less steady tempo and extensive drum fills.

We found only three Stones studio recordings where at least 40 percent of the beat 2 attacks were *early* by at least 2.5 percent of mean IOI: "If You Can't Rock Me" (1974), "Hot Stuff" (1976), and "Brand New Car" (1994). "If You Can't Rock Me" features a simple, unsyncopated kick pattern—often using just single attacks on beats 1 and 3—and a relatively busy snare drum with frequent fast fills. "If You Can't Rock Me" is the earliest Stones track we found with a mean beat 2 delay of less than zero (indicating that beat 2 attacks were on average early) with all 27 analyzed tracks released prior to 1974 having a mean beat 2 delay greater than zero. In contrast, of the 19 analyzed tracks from 1980 onwards, eight of them (42 percent) have negative beat 2 mean deviations. "Hot Stuff," a disco track that is one of the band's steadiest



Example 14

Deviation of beat 2 from expected position (based on average beat length in the previous bar) in the first four minutes of "Let It Loose." Gaps in the graph indicate no drum part at that moment (audio example, 2:25–3:23).

recordings prior to the 1980s (tempo CV of 0.66; see section V, below), similarly features a very simple kick pattern with single attacks on beats 1 and 3, as does the later "Brand New Car." Iyer wrote that the four-on-the-floor kick drum approach, another pattern associated with disco that involves no syncopation or eighth notes in the kick, was incompatible with delayed backbeats because it eliminated or at least reduced the timbral difference between the downbeats and the backbeats (2002, 406), yet its incompatibility with backbeat delay and its complement, an early kick, may be more related to the simplicity of its kick pattern. The Stones song "Emotional Rescue" exemplifies the tendency towards early backbeats when a four-on-the-floor pattern is used, as the verse four-on-the-floor pattern shows a significant tendency towards an early beat 2 and the backbeat pattern in the bridges and outro lacks this tendency (see Appendix Example 1).

Looking at microtiming in Rolling Stones live recordings with Watts, there are also instances of relatively consistent backbeat delay, with 7 out of 19 recordings having at least 40 percent of their beat 2 attacks meeting the 2.5 percent JND threshold and 10 recordings meeting that standard for beat 4 (Example 15). The band's 1973 Brussels rendition of "Gimme Shelter" had the most consistently delayed second beats, while the four live recordings of "Tumbling Dice" we analyzed showed a pattern of backbeat delay similar to that in the studio recording. The consistency with which the Rolling Stones have performed this song with delayed backbeats in both studio and live settings suggests that the approach is a crucial component of it. Watts's use of delayed backbeats

Song Title	Year	Mean Temp	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)								Portion Analyzed	*n*
			Bt. 2 JND Early %	**Bt. 2 JND Late**	Bt. 4 JND **%**Early %	Bt. 4 JND Late %	Bt. 1 *M*	Bt. 2 *M*	Bt.2 *SD*	Bt. 2 *p*	Bt. 2 % of IOI	Bt. 3 *M*	Bt. 4 *M*	Bt. 4 % of IOI		
Gimme Shelter (Brussels)	1973	131	5	**64**	12	57	-1	15	14	<.00	3.2	1	16	3.5	0:00-2:06	66
Tumbling Dice (Brussels)	1973	114	2	**58**	14	53	-5	17	15	<.001	3.3	-1	13	2.5	0:02-1:35	43
Tumbling Dice (Wembley)	1982	119	7	**54**	36	51	-3	11	16	<.001	2.1	4	9	1.9	full song	82
Shine a Light (Amsterdam, Honk Comp.)	2017	81	9	**43**	23	45	1	11	21	0.02	1.5	11	15	2.1	0:50-2:00	23
Angie (Stripped)	1995	77	4	**43**	39	39	0	13	26	0.02	1.7	6	5	0.7	0:40-1:56	23
Tumbling Dice (LA Forum)	1975	113	10	**43**	31	45	-7	8	18	0.005	1.6	-5	8	1.7	0:02-1:36	42
Slipping Away (Stripped)	1995	94	10	**42**	25	47	-1	11	20	<.001	1.7	5	10	1.6	0:11-2:15	52
Stray Cat Blues (Get Yer Ya-Yas Out)	1969	83	20	**37**	29	50	-9	13	20	<.001	1.9	11	11	1.5	0:07-2:03	38
Black Limousine (Wembley)	1982	121	10	**36**	22	32	-2	8	16	<.001	1.5	2	6	1.3	full song	100
Wild Horses (Stripped)	1995	73	8	**35**	39	42	-6	11	22	0.005	1.3	-8	3	0.4	0:02-1:18 & 3:16-4:08	&37
Gimme Shelter (No Security)	1997	118	3	**34**	24	47	-1	9	12	<.001	1.8	5	8	1.7	0:33-1:47	35
The Spider and the Fly (Stripped)	1995	92	23	**31**	32	37	-6	4	23	0.29	0.6	10	0	0.1	0:05-1:48	39
Memory Motel (No Security)	1998	88	4	**30**	27	27	-1	13	24	0.02	1.9	7	0	0.1	0:56-2:03	23
Tumbling Dice (Love You Live)	1976	111	12	**30**	21	37	-8	7	15	0.01	1.2	1	8	1.6	0:00-1:37	43
Beast of Burden (Wembley)	1982	111	6	**23**	22	36	-1	6	12	<.001	1.1	3	5	1.0	0:00-3:00	80
Hot Stuff (Love You Live)	1976	109	10	**21**	12	39	0	2	12	0.31	0.4	-5	7	1.3	0:07-1:40	42
Heart of Stone (Toronto Rehearsal)	2002	55	2	**21**	12	45	-6	14	20	<.001	1.3	8	15	1.4	0:00-2:30	43
Little Queenie (Get Yer Ya-Yas Out)	1969	125	22	**10**	30	21	-1	-1	13	0.35	-0.3	-1	-3	-0.6	0:06-2:17	67
I Got the Blues (Fonda Theatre)	2015	46	24	**5**	46	24	-15	-12	30	0.02	-0.9	-7	-18	-1.3	full song	38
Mean	1987.7	97.9	10.1	34.7	26.1	40.7	-3.8	8.4	18.4		1.4	2.5	6.2	1.2		48.2
Standard Deviation	14.7	24.1	7.1	15.1	9.5	9.5	4.1	6.7	5.2		1.0	5.9	7.9	1.1		21.3
Median	1982	109	9	35	25	42	-2	11	18		1.5	3	8	1.4		42
Minimum	1969	46	2	5	12	21	-15	-12	12	<.001	-1	-8	-18	-1.3		23
Maximum	2017	131	24	64	46	57	1	17	30	0.35	3	11	16	3.5		100

Example 15

Microtiming in 19 Rolling Stones live recordings, ordered by percentage of beat 2 attacks that are 2.5% or more of the mean IOI late. The "Beat 2 JND Early" and "Late" percentages refer to the frequency of deviations that are 2.5% of the average IOI or larger. "Bt. 2 %" translates the raw beat 2 delay into a percentage of the mean IOI for the song; "*n*" refers to the number of beat 2 attacks analyzed. The *p*-value is the result of a one-sample *t* test with a null hypothesis that the beat 2 mean deviation is 0.

in live performances of several Stones songs continued even through the era in which he largely gave up playing with delayed backbeats in the studio, as live recordings of "Shine a Light," "Angie," "Gimme Shelter," and others from the 1990s and twenty-first century attest.

In order to better understand how Watts's microtiming tendencies compare with those of his contemporaries, we also analyzed 59 recordings with other drummers (Appendix Example 2). Prior to 1979, other drummers delayed by at least 2.5 percent of mean IOI an average of 20 percent of second beats, while from 1979 on this number fell to just 8 percent (Example 16). On average, other drummers prior to 1979 delayed beat 4 slightly less than beat 2, though not to a statistically significant extent ($p = .10$).[24] We found a relatively small number of recordings of other drummers, all but one from prior to 1979, with a tendency towards substantial delay (Example 17). While just three recordings we analyzed had more than 50 percent of their second beats substantially delayed (including the famous eight bars of James Brown's "Funky Drummer"), several more prior to 1979 had an average beat 2 delay of at least 2.5 percent of mean IOI, including "Easy" by the Commodores (1977), "Hey Joe" by the Jimi Hendrix Experience (1966), and "Take Me to the River" by Talking Heads (1978). Al Jackson Jr., who Max Weinberg referred to as a pioneer of playing behind the beat (Beaumont-Thomas 2021), delays beat 2 consistently on "Green Onions" and to a lesser extent on Sam & Dave's "Hold On, I'm Comin'," but not on "It Ain't No Fun to Me," "In the Midnight Hour,"[25] "Knock on Wood," "Soul Man," or "I Never Found a Girl." As with the Stones recordings that show a strong tendency towards backbeat delay, recordings by other artists that have the highest average beat 2 delays still have relatively high standard deviations, reflecting how the exact *amount* of delay is highly variable even when there is a strong tendency towards playing behind the beat.

When comparing Watts's practices with those of other drummers in the two full sets of data, it appears that Watts much more commonly delayed beat 2 at least 2.5 percent of mean IOI (Example 18). Overall, he substantially delayed the second beat 29 percent of the time, while other drummers did so only 15 percent of the time ($p < .001$). This holds true also when looking only at releases prior to 1979, a timeframe when

24 In his study of microtiming in famous breakbeats, Frane found significantly more tendency to delay beat 2 than beat 4 (2017, 299), but we did not find this to a statistically significant extent with either Watts or the group of other artists.

25 "In the Midnight Hour" is famous as a supposed example of a delayed backbeat (Bowman 1995, 308–309; Covach and Flory 2018, 235–236). But the analyses of Smialek (2020) and Hosken (2021) concur with ours that the snare in this recording does *not* have a consistent pattern of delay. One possible reason for the perception of backbeat delay in this track is the playing of the horn section on the backbeats, sounding slightly later than the snare hits.

	Mean Year	Mean Tempo	Accumulated, Previous				p		Accumulated Deviation, Relative to Previous (Means in ms)							#m.	# songs
			Bt. 2 JND Early %	Bt. 2 JND Late %	Bt. 4 JND Early %	Bt. 4 JND Late %	Others 1979 on	Watts Pre-1979	Bt. 1	Bt. 2	Bt. 2	Bt. 2 % of IOI	Bt. 3	Bt. 4	Bt. 4 % of IOI		
Others Pre-1979	1970	103	8.1	19.8	24.6	23.5	0.003	0.002	-1.3	4.1	12.8	0.6	3.1	1.0	0.1	41	36
Others 1979 on	1997	100	15.1	8.3	20.9	14.7	x	x	-0.6	-2.7	9.5	-0.4	2.3	-2.7	-0.4	46	23
Watts Pre-1979	1972	105	9.7	33.3	21.8	36.0	x	x	-3.1	8.8	16.6	1.4	3.6	7.2	1.2	45	43
Watts 1979 on	1994	112	11.6	20.6	24.8	31.8	0.003	0.01	-1.2	3.2	14.3	0.5	0.2	2.8	0.5	43	19

Example 16

Comparison of microtiming means in other drummers and in Charlie Watts. "Bt. JND Early %" and "Late" refer to the mean percentage of second or fourth beats that are at least 2.5 percent of mean IOI early or late. "Bt. 2 %" translates mean beat 2 deviation into a percentage of mean beat length; "#m." indicates the mean number of second beats analyzed in the songs.

Song Title	Artist	Year	Mean Tempo	Accumulated, Previous		Accumulated Deviation, Relative to Previous (Means in ms)						Portion Analyzed	*n*
				Beat 2 JND Late %	Beat 4 JND Late %	Bt. 2 *M*	Bt. 2 *SD*	Bt. 2 *p*	Bt. 2 % of IOI	Bt. 4 *M*	Bt. 4 % of IOI		
Funky Drummer	James Brown	1970	101	**63**	13	18	6	**<.001**	3	0	-0.1	famous 8 bars	8
And Your Bird Can Sing	The Beatles	1966	133	**61**	50	12	15	**<.001**	2.6	7	1.5	0:00-0:54	62
The Weight (live)	Joe Cocker	1970	75	**55**	38	20	20	**<.001**	2.4	10	1.3	0:00-1:24	22
Easy	Commodores	1977	66	**46**	42	17	18	**<.001**	1.8	13	1.4	0:15-2:30	26
Green Onions	Booker T. & the M.G.s	1962	137	**46**	15	10	7	**<.001**	2.4	1	0.2	full song	89
Hey Joe	Jimi Hendrix	1966	83	**37**	27	13	23	0.005	1.9	20	2.0	0:08-1:38	30
Take Me to the River	Talking Heads	1978	99	**35**	42	12	8	**<.001**	1.9	8	1.4	0:00-0:51	20
53rd & 3rd	Ramones	1976	135	**34**	45	4	21	0.268	0.8	4	1.1	0:00-1:20	44
This Forgotten Town	The Jayhawks	2020	79	**33**	34	13	19	**<.001**	1.8	5	0.7	0:05-2:05	39
I Can't Quit You Baby	Led Zeppelin	1969	54	**30**	42	17	20	0.001	1.5	19	1.8	0:00-1:32	20
Mean (all 59 recordings by others)		1980.7	101.6	15.3	20.1	1.4	11.5		0.2	-0.5	-0.1		43.3
Standard Deviation		16.9	26.4	16.1	13.1	2.4	5.9		1.3	8.1	1.1		26.0
Median		1977	106	9	19	3.4	11		0.2	-2	-0.2		38
Minimum		1957	49	0	0	-23	1	**<.001**	-3.8	-18	-3.4		7
Maximum		2023	163	63	50	20	26	0.99	3	20	2		121

Example 17

Songs by other artists with the largest percentage of beat 2 attacks that are delayed at least 2.5 percent of the average IOI, sorted by percentage of delayed attacks meeting that standard. "Bt. %" translates raw beat delay into a percentage of the mean beat length. The *p*-values for beat 2 deviation means are the result of two-sided one-sample *t*-tests as compared to a null hypothesis value of zero; *n* indicates the number of beat 2 attacks analyzed in the song.

Drummer	Year Mean	Tempo Mean	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)							#m.	# songs
			Bt. 2 JND Early %	Bt. 2 JND Late %	Bt. 4 JND Early %	Bt. 4 JND Late %	Bt. 1 *M*	Bt. 2 *M*	Bt. 2 *SD*	Bt. 2 % of IOI	Bt. 3 *M*	Bt. 4 *M*	Bt. 4 % of IOI		
Others	1980.7	101.6	10.8	15.3	23.2	20.1	-1.0	1.4	11.5	0.2	2.8	-0.5	-0.1	43	59
Watts	1978.9	107.5	10.3	29.4	22.7	34.7	-2.5	7.1	15.9	1.1	2.5	5.9	1.0	44	62

Example 18

Comparison of microtiming means in other drummers and in Charlie Watts (all years). “Bt. 2 JND Early %” and “Late” refer to the mean percentage of second beats that are at least 2.5 percent of mean IOI early or late. “Bt. 2 % of IOI” translates mean beat 2 deviation into a percentage of mean beat length; “#m.” indicates the mean number of second beats analyzed in the songs.

both sets of data showed more consistent beat 2 delays (Example 16). Prior to 1979, Watts substantially delayed an average of 33 percent of his second beats (45 percent in the 1967–73 period) and other artists only substantially delayed 20 percent ($p = .002$). Watts delayed beat 4 approximately the same amount as beat 2, while other drummers on average showed no significant tendency to delay beat 4. The mean percentage delay of Watts's second beats prior to 1979 was 1.4 percent (2.4 percent during 1967–73), while other drummers prior to 1979 had just 0.6 percent mean delay ($p = .01$).[26] After 1978, Watts continued to show a significantly greater tendency to delay beat 2 and beat 4 than other drummers, though with both corpora, the delays were smaller and less consistent from 1979 onwards. In fact, other drummers from 1979 and after show a slight tendency to *anticipate* both beat 2 and beat 4. Overall, there is significant evidence that Watts delayed backbeats to a greater degree and more frequently than his contemporaries, with the tendency particularly strong between 1967 and 1973, a period of time that nearly matches Jimmy Miller's tenure as the Stones' producer (1968–1973).

IV. Tempo Variability: Patterns

We turn now to tempo variability in the music of the Rolling Stones in order to further elucidate the reality behind the myths regarding Charlie Watts. After a brief discussion of prior scholarship and our methodology, we identify four primary models of tempo curve for the band's music and closely examine tempo variability in two examples.

In classical music, tempo fluctuations such as ritardandi, accelerandi, and rubato are accepted as conventional musical elements. Tempo variability in performance of classical repertoire has been studied by multiple scholars, including Repp, who uses the term "timing microstructure" to refer to the "continuous modulations of the local tempo" that occur in classical performance, particularly in Romantic-era repertoire (1995, 40). Yet mainstream popular music in the twentieth and twenty-first centuries, particularly that dating from after the start of the rock 'n' roll era in 1955, is generally assumed to have a steady tempo—even a metronomic approach. Human drumming without a metronome, however, involves small fluctuations in tempo that can act expressively, and commentators have argued that such fluctuations characterized Watts's performances.[27]

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26 Watts also delayed backbeats more than other drummers when playing the same song. While Watts's studio version of "Heart of Stone" substantially delays 25 percent of the second beats, beat 2 attacks in the *Metamorphosis* version of the song with substitute drummer Clem Cattini are on average slightly ahead of expectation. The Stones' cover of "I'm a King Bee" substantially delays 50 percent of the second beats, while the original shows no statistically significant tendency towards beat 2 delay. Similarly, covers of Stones songs by Linda Ronstadt ("Tumbling Dice") and Blackberry Smoke ("All Down the Line") do not show the same propensity for delayed backbeats as the originals.

27 Tempo fluctuations in Watts's drumming occur within the context of the Rolling Stones as a band, so

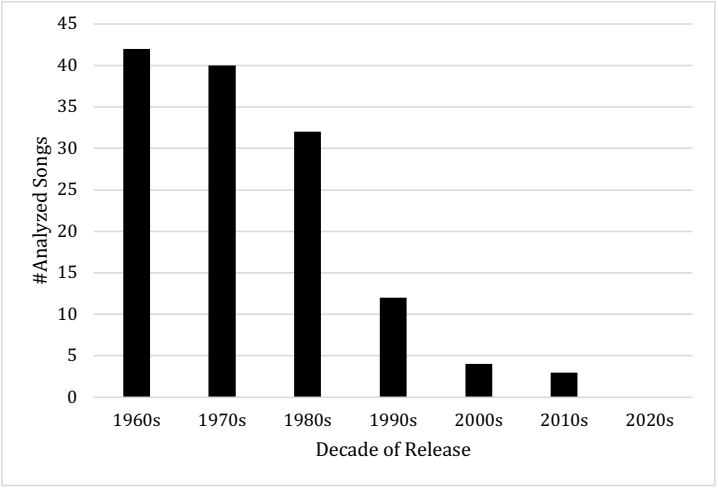
In order to better understand tempo variability in the playing of Watts and the Rolling Stones, we used Celemony's Melodyne 5 Studio software to detect attack transients and automatically generate a tempo map showing the tempo at all points in a song (Example 19).[28] This tempo map shows where the band speeds up or slows down and allows recognition of patterns. While these automatically generated tempo maps are mostly reliable, the algorithm can sometimes have difficulty staying with the beat when there are no drums playing or if there are ritardandi. Therefore, we listened to each song while looking at the tempo map and made corrections wherever necessary.[29] Looking at the shapes of 133 Stones studio recordings on which Charlie Watts played drums (Appendix Example 3; Example 20), we were able to identify four primary models for tempo variability.

it is necessary to look at the band as a whole in this regard. Because one aspect is individual and the other is collective, one must be cautious in making direct comparisons between analysis of microtiming in Watts's drumming and analysis of the tempo variability of the entire band. We nevertheless present analyses of drum microtiming and tempo variability side by side because they are so closely interrelated and together provide a more complete picture of Watts's drumming.

28 Polfreman (2013) evaluated the ability of an earlier version of Melodyne to track attack transients, finding that it identified percussive attacks well but showed significant discrepancy from perceptual attack times for bowed sounds (4–5).

29 In about half of the cases, it was necessary to manually enter the correct time signature, correct "octave" errors if the algorithm misinterpreted the tempo as being half or twice as fast (Schreiber 2020, 29), or make other manual adjustments. While another analyst might end up with slightly different tempo maps, this would not substantially affect the overall shapes described in this section. See footnote 33, below, regarding potential variability in tempo coefficient of variation calculations by different analysts using Melodyne.

Example 19
A tempo map in Melodyne.



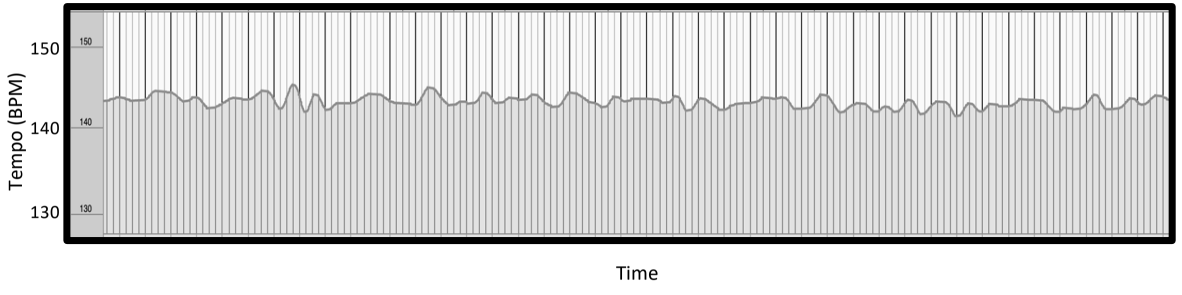
Example 20

Distribution by decade of the 133 Rolling Stones studio recordings with Charlie Watts analyzed for tempo variability, including the total number of studio albums the band released in each decade (excluding albums prior to 1968 that were duplicates created for an alternate market).

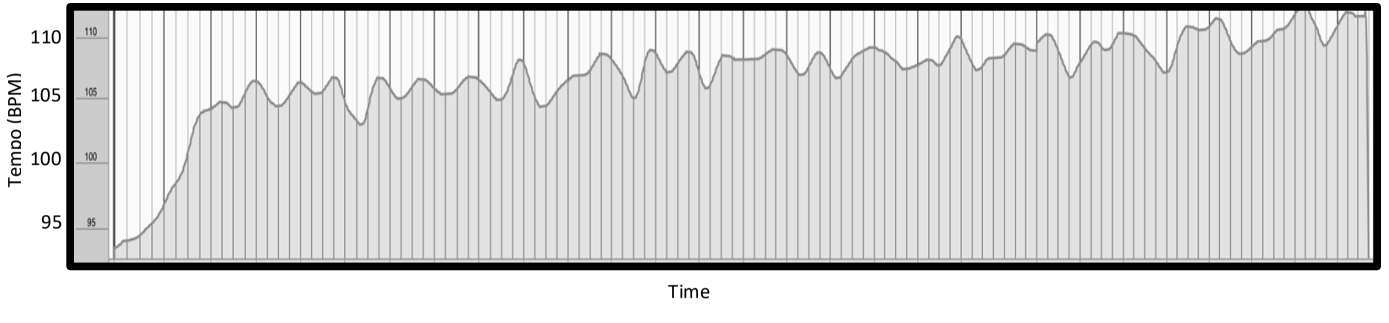
In the first model, the tempo is a relatively flat line (Example 21). There may be some small ups and downs, but the tempo stays within a relatively narrow range. This approach can be heard in the songs "Harlem Shuffle" (1986), "Mixed Emotions" (1989), and "Terrifying" (1989), though a relatively flat line is rare for the band, especially prior to the 1980s.

The second shape can be found more often in their '60s and '70s recordings: here the band significantly increases the tempo within the first handful of bars, then is relatively steady after that point. This pattern is heard in "Sweet Virginia" (Example 22), where the guitars start at 93 BPM and quickly reach 106 BPM within just 12 bars. This kind of early acceleration occurs also in "Stray Cat Blues," "Dancing with Mr. D," and in 1970s live versions of "Honky Tonk Women," "Brown Sugar," "Jumpin' Jack Flash," and "Tumbling Dice." We observed early acceleration in other artists' studio recordings as well, including in the Jimi Hendrix Experience's "All Along the Watchtower" and Creedence Clearwater Revival's "Born on the Bayou."

A third pattern found in Stones studio recordings from the 1960s and '70s involves a continuous increase in tempo throughout a song. Examples include "Salt of the Earth," "You Can't Always Get What You Want" (on which Jimmy Miller



Example 21
Tempo map for "Terrifying" (1989), showing a relatively flat line (Low: 142 BPM; High: 145 BPM; Range: 2%).



Example 22
Tempo map of "Sweet Virginia" (1972), illustrating a pronounced early acceleration followed by relative steadiness afterwards (video example). ▶

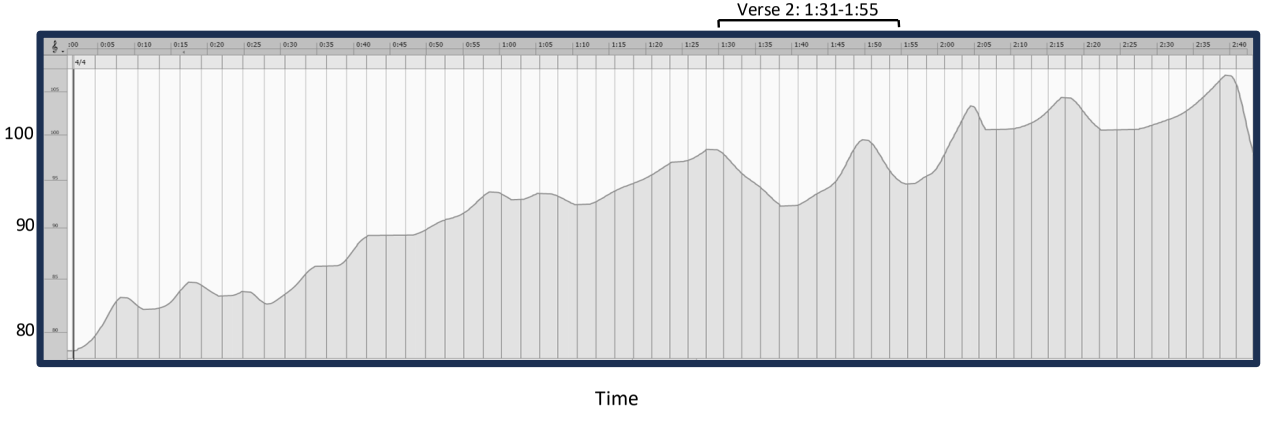
substituted for Watts), "Honky Tonk Women," and "You Got the Silver." As shown in Example 23, "You Got the Silver" starts at 78 BPM and has an almost continuous acceleration until it reaches 107 BPM by the end, an increase of 37 percent. Such gradual accelerations are consistent with findings that a drift towards faster tempos is common in musical performances generally (Merker et al. 2009, 9). "Salt of the Earth" and "You Can't Always Get What You Want" also illustrate how the building of instrumental texture is often associated with tempo acceleration, consistent with observations that greater loudness and fuller textures are associated with greater speed (e.g., Huron 2006, 323–324).[30]

A fourth approach is for the tempo to vary according to the formal sections of the song. For instance, the band sometimes speeds up to the end of a verse and then slows down for the beginning of the next verse. This pattern may repeat several times throughout a song, especially with a series of 12-bar-blues strophes or with A sections in a 32-bar AABA form. Such sectional tendencies are reminiscent of those identified by Räsänen et al. in their study of Michael McDonald's "I Keep Forgettin'" (2015, 7–8). Example 24 shows the Stones' 1964 cover of Gene Allison's "You Can Make It If You Try," in which these sectional accelerations reinforce the formal structure of the song. In verse-chorus songs, an acceleration at the end of the verse is typically maintained in the chorus, with the tempo then coming back down for the start of the next verse, as in the Stones' "Shine a Light" (on which Jimmy Miller took the place of Watts). Such accelerations at the ends of verses leading into choruses are examples of acceleration as anacrusis, building excitement as a structural point of arrival approaches. Bridges, on the other hand, can be significantly slower than surrounding sections. Examples include the bridges in "Rocks Off," "Have You Seen Your Mother, Baby, Standing in the Shadow?," and "Let's Spend the Night Together." In "Shine a Light" (Example 25), the tempo slows for a brief instrumental breakdown, then the texture and tempo rebuild to a climactic final chorus.[31]

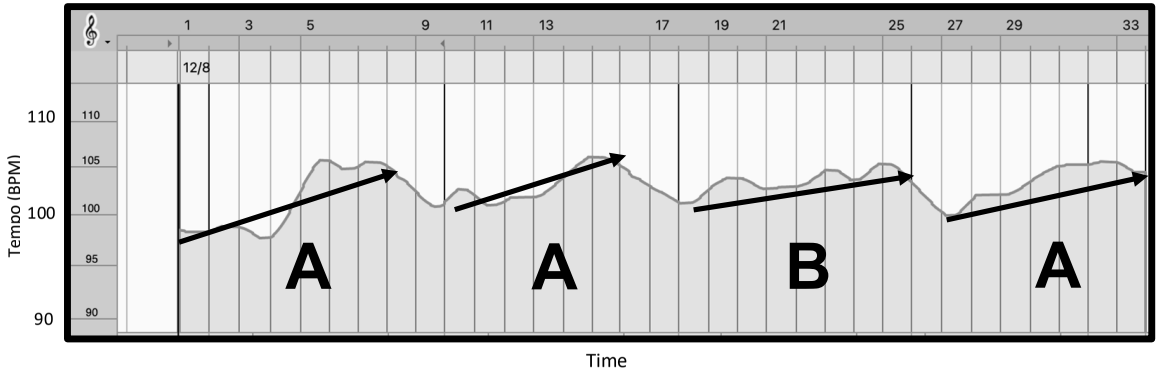
Apart from these four shapes, we can also observe tempo fluctuation on a more local level, from one bar to the next, when Watts plays a drum fill. Consistent with the tendencies of most drummers, he would slightly accelerate during his fills and then immediately return to a slower tempo, as can be heard in the 2004 live recording of

30 Baur discusses the combination of increasing texture and tempo in "Salt of the Earth" (2020, 37–38). We did not find examples where the Stones significantly slowed down over the course of a song. Other artists also speed up much more commonly than they slow down, with accelerating examples including "I'm So Tired" by the Beatles, "Hells Bells" by AC/DC, and "Babies" by Pulp.

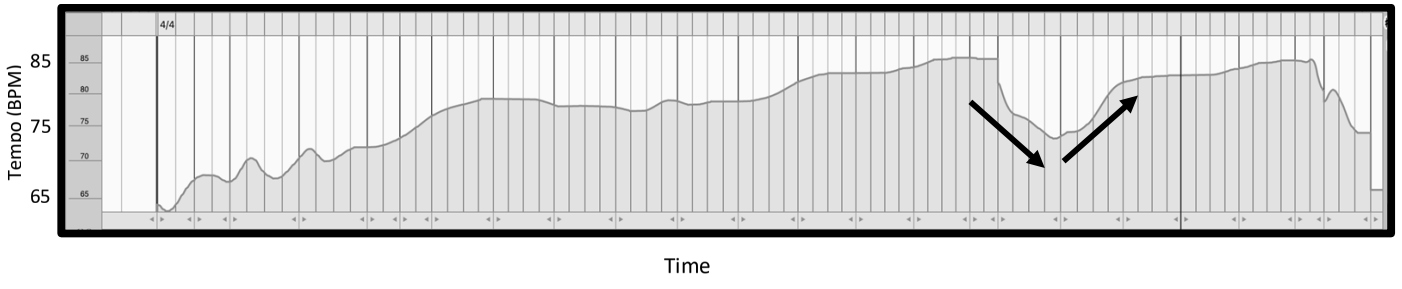
31 Huron has noted the tendency of performers to accelerate as they approach a climactic moment (2006, 326).



Example 23
Tempo map for "You Got the Silver" (video example, 1:25–2:15).

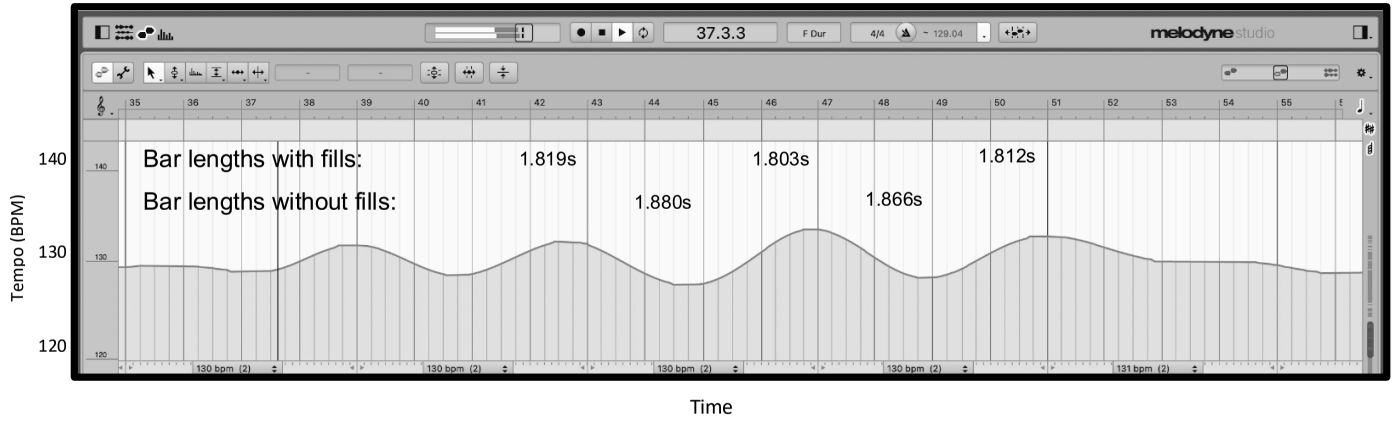


Example 24
Tempo map of the Rolling Stones' cover of "You Can Make It If You Try" (1964), illustrating sectional acceleration in an AABA form.



Example 25

Tempo map of "Shine a Light" (1972; Jimmy Miller on drums), illustrating a slowing of tempo from 85 BPM to 73 BPM during the instrumental breakdown, followed by a gradual rebuild (video example, 2:52-3:27). ▶



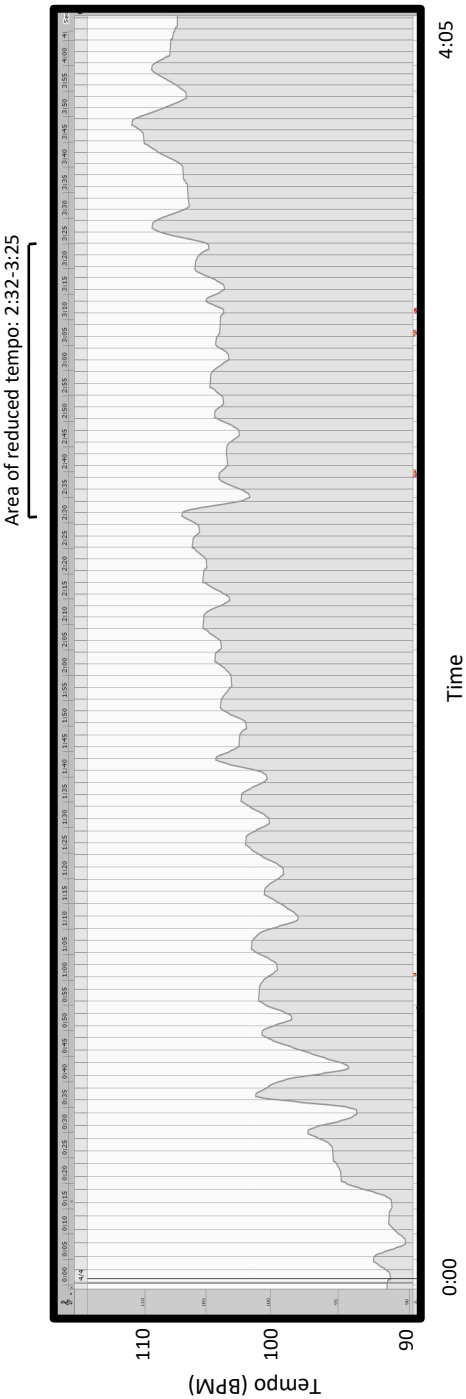
Example 26

Tempo map for the Rolling Stones' 2004 live recording of "Start Me Up" (*Live Licks*, 2004), illustrating tempo acceleration during drum fills (video example, 1:09-1:33). ▶

"Start Me Up" from the *Live Licks* compilation (Example 26). This speeding up in preparation for a structural downbeat is another form of anacrustic acceleration (cf. Attas 2015, 289; Dodson 2011, 61). This is the opposite of what typically happens to tempo at the ends of classical music phrases (as well as in popular ballads), where it is more common to slow down as a cadence is approached (see, for example, Senn et al. 2012, 33).

Looking in greater detail at tempo variability in two Stones songs—"You Got the Silver" and "Monkey Man"—shows how larger-scale patterns of tempo change interact with more local variation. In "You Got the Silver" (Example 23), there is an almost constant pattern of acceleration tied to the building of texture, with one significant deceleration that interrupts this large-scale arc. This deceleration begins at 1:31, immediately after a slide electric guitar solo section featuring the full band. At this point Richards starts another verse, now accompanied only by an acoustic guitar. With the texture reduced, the tempo substantially slows. There is a local acceleration at 1:41 when an acoustic slide guitar joins the texture, and this acceleration continues when an electric slide guitar enters at 1:46, but the tempo begins to drop again at 1:50 when the texture is again reduced to a solo acoustic guitar. A more permanent, substantial acceleration only begins when the full band returns with a louder new verse at 1:55. This verse features not only the full slate of instruments but also Richards's vocals an octave higher and reaches a tempo of 100 BPM for the first time at 2:02. The fastest tempo in the song (107 BPM) is achieved near its end, between 2:40 and 2:43, before a final, brief ritardando.

Another recording with a nearly continuous pattern of acceleration is "Monkey Man" (Example 27), a song whose microtiming we discussed in section III, above. The recording reflects interactions between tempo variability and microtiming deviations. From the perspective of tempo variability, the gradual increase from 91 to 110 BPM over the course of the song is essentially uninterrupted except for a significant structural drop in the second half and some rapid alternation near the very end (starting at 3:29). The area of decreased tempo runs from 2:32 to 3:25. It contains a slight gradual increase within it but represents a trough in the overall curve of the song. The start of this trough correlates with the start of the second portion of the instrumental break at 2:34, where the key changes from C♯ major to E major and a new chord loop of I–V–IV–V is used. The tempo drop and modulation also correlate with the second-most delayed beat 2 in the song, the first beat 2 after the modulation, which comes after a period of relatively consistent microtiming in the first portion of the instrumental break. Most of the area of decreased tempo occurs during the E major instrumental section; at 3:11, the key returns to C♯ major and Jagger starts a series of "I'm a monkey" exclamations as the



Example 27
Tempo map of the Rolling Stones' "Monkey Man" (audio example, 2:25–3:18).

tempo continues to accelerate. The closing (3:29 to the end) features wide tempo swings and sounds chaotic, with lots of drum fills, vocal improvisations, and all instruments very active.

V. Measuring Tempo Variability in the Rolling Stones

In addition to identifying patterns of tempo fluctuation in songs, we developed a method to precisely measure tempo variability. Here, we discuss the method as well as our findings for both Watts and other artists.

Building on the approaches to assessing tempo variability employed by Roessner (2017, 1–2), Schreiber (2020, 85–86, 118–119), and Condit-Schultz and Clark (2024, 4–5, 7–8), we used two methods to measure this aspect, one straightforward but limited, the other more sophisticated and nuanced. First, we used Melodyne to determine the difference between the tempos of the slowest and fastest parts of each song, calculating the song's tempo range as a percentage of the slowest tempo in the song. Example 28 shows the Stones studio tracks with the largest percentage tempo increases as measured by this method. This approach provides an overview of the variability of the song, though it has limitations in the information it conveys because it does not indicate how much time is spent in the extremes or whether the variability is consistent or isolated.

Song	% Increase
You Got the Silver	32
Salt of the Earth	28
Wild Horses	26
Factory Girl	23
Sister Morphine	21
Love in Vain	20
You Gotta Move	20
Stray Cat Blues	18
Memory Motel	17
I Got the Blues	17

Example 28

The Rolling Stones studio tracks with the largest accelerations, calculated as a percentage increase from the slowest to the fastest tempo in the song. "Salt of the Earth" calculation assumes a normal-time feel in the coda.

We therefore also used a method that determined the local tempos throughout the song, then assessed how much variability there was in these numbers over the course of

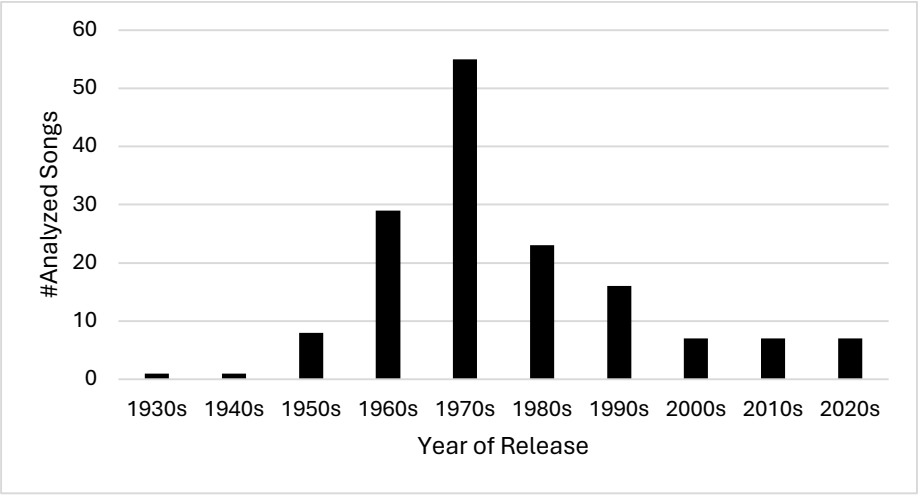
the entire recording. We began by using Melodyne to generate a tempo map, as described in section IV, above. We then exported this tempo map as a MIDI file into Apple's Logic Pro (a digital audio workstation) where it could be transformed into audio by turning on the metronome within the software. The metronome audio would then be bounced to an audio file that we imported into Sonic Visualiser. Within Sonic Visualiser, we used the BBC Rhythm: Onsets plugin to place a marker on each beat of the metronome, then exported this annotation layer as a CSV (comma-separated values) file into Excel. We used Excel to compute the local tempo of each set of two consecutive bars in the song,[32] then calculated the standard deviation of these local tempo values. After determining the standard deviation of all local tempo measurements, we calculated the coefficient of variation, also known as the *relative* standard deviation. The coefficient of variation, or CV, is determined by dividing the standard deviation of the local tempo values by the mean tempo for the song, thereby allowing comparisons on the same scale of songs with different tempos. We multiplied this value by 100 in order to state it as a percentage. A CV of zero would indicate no change in tempo throughout the song. The Stones' "Saint of Me," for which Watts played along to a drum machine, has a CV of 0.29, while CV values of 2.0 or higher reflect a freer approach to tempo, with potential use of expressive rubato or clearly audible tempo changes (as in "You Got the Silver" [CV = 7.42] and "Sweet Virginia" [6.91]).[33]

We calculated the tempo CV of 133 studio and 28 live recordings by the Rolling Stones as well as 304 recordings by other artists to compare them to, including the 10 biggest hits on the *Billboard* year-end charts for selected years between 1966 and 2021 (see Appendix Examples 3–5 and Example 34, below). We made a representative selection of studio recordings from each decade of the Stones' career, as seen in Example 20, also selecting songs with a variety of different tempos and genres. The 28 live recordings were selected in order to get a mix of different chronological periods and tempos. We also analyzed multiple live performances of the same song in order to get an idea of how much tempo variability would vary by concert and decade. Besides the *Billboard* corpus, we selected 154 additional songs with other drummers that could be considered rough parallels in genre and time period to the songs in the Stones corpus, including seven Rolling Stones songs on which Watts was replaced by another drummer or otherwise did not play. The distribution of these songs by decade is seen in Example 29. This corpus also included some non-rock songs that were selected to help us better

32 We used sets of two bars in order to approximate the window in which a listener perceives tempo. Schreiber points out that there is a lack of scholarly consensus on the timeframe within which tempo perception occurs. His approach is to use a 12-second window (2020, 115–117, 119).

33 There is potential variability in different analysts' tempo CV calculations, even when our detailed method is followed, particularly in cases of songs with prominent ritardandi and/or caesuras. Analysis of the same tracks

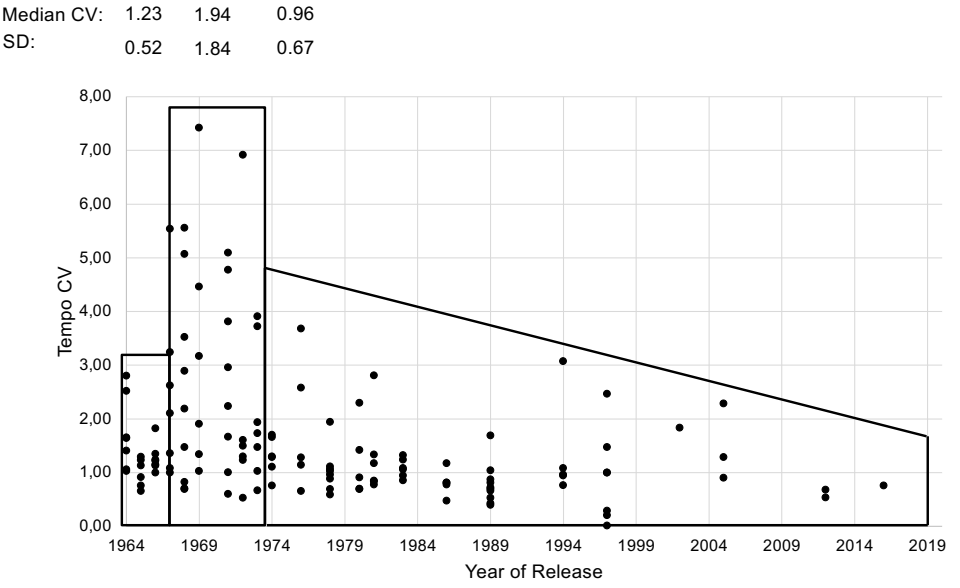
determine the ranges of CV values associated with the use of technological implements such as click tracks, loops, and drum machines.



Example 29
Distribution by decade of 154 recordings with other drummers (excluding the *Billboard* Top 10 sample) analyzed for tempo variability (CV).

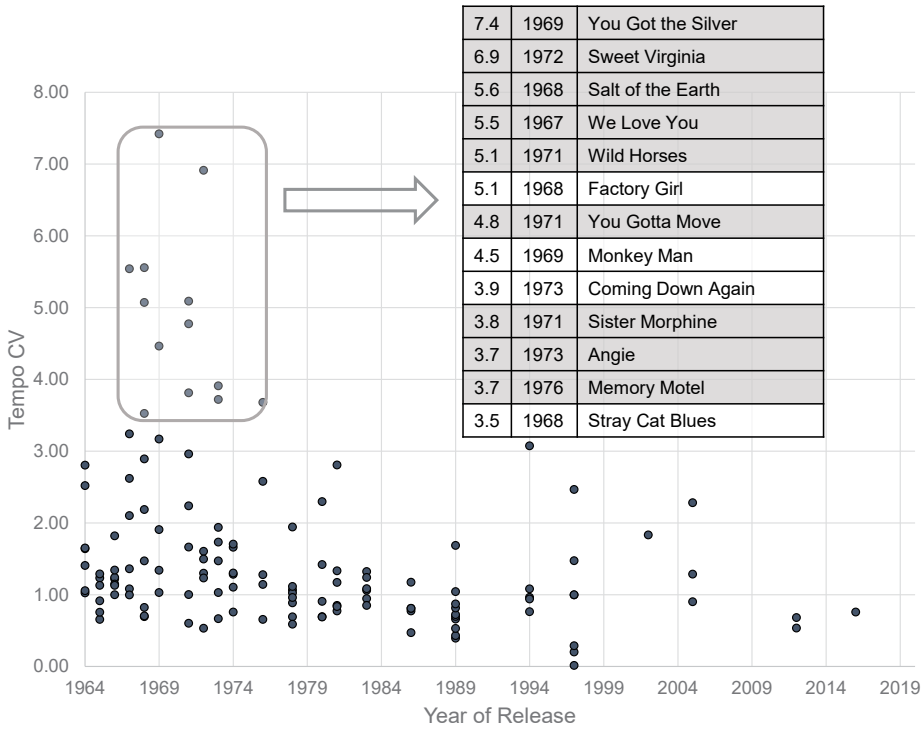
Analysis of the Stones' studio songs shows that the band's career with Watts as drummer can be divided into three periods, based on the approach to tempo variability (Example 30; see also Example 35, below). In the first period, from the start of their career through early 1967, Watts and the Stones mostly maintained a steady tempo in their songs, though without metronomic precision. In this period, they often used tempo to delineate formal structure, so they might speed up slightly for a chorus but return to the original tempo for the next verse, consistent with the fourth tempo approach described in section IV, above.

by different analysts suggests that analyses of songs with a CV of 1.0 or below will typically be identical or nearly identical, while independent analyses of recordings with tempo CVs greater than 1.0 can differ by up to 10 percent.



Example 30
Tempo CV measurements of Rolling Stones songs with Watts by year, showing division into three periods.

The second period began with their August 1967 release of the single "We Love You." 1967 was a transitional year for the Stones, in which they released two albums, *Between the Buttons* in January and *Their Satanic Majesties Request* in December. The tracks on *Between the Buttons* mostly have a steady tempo, while those from the self-produced psychedelic *Their Satanic Majesties Request*, such as "Citadel" (CV = 3.24), tend to have large tempo variability, with suite-like structures, fermatas, and rhythmically free sections lacking an isochronous pulse. The "We Love You" single and *Their Satanic Majesties Request* thus inaugurated a second period, running from mid-1967 to 1973, in which the Stones exhibited much more tempo variability in their studio recordings. After *Their Satanic Majesties Request*, from 1968 through 1973, when the band was produced by drummer Jimmy Miller and released some of their most celebrated albums, they showed a pronounced tendency to accelerate. Example 31 lists the Stones' songs with the highest tempo CV values that we found for the band. All 13 of these songs are from the band's Jimmy Miller period, the era in which they also showed the greatest penchant for delayed backbeats.



7.4	1969	You Got the Silver
6.9	1972	Sweet Virginia
5.6	1968	Salt of the Earth
5.5	1967	We Love You
5.1	1971	Wild Horses
5.1	1968	Factory Girl
4.8	1971	You Gotta Move
4.5	1969	Monkey Man
3.9	1973	Coming Down Again
3.8	1971	Sister Morphine
3.7	1973	Angie
3.7	1976	Memory Motel
3.5	1968	Stray Cat Blues

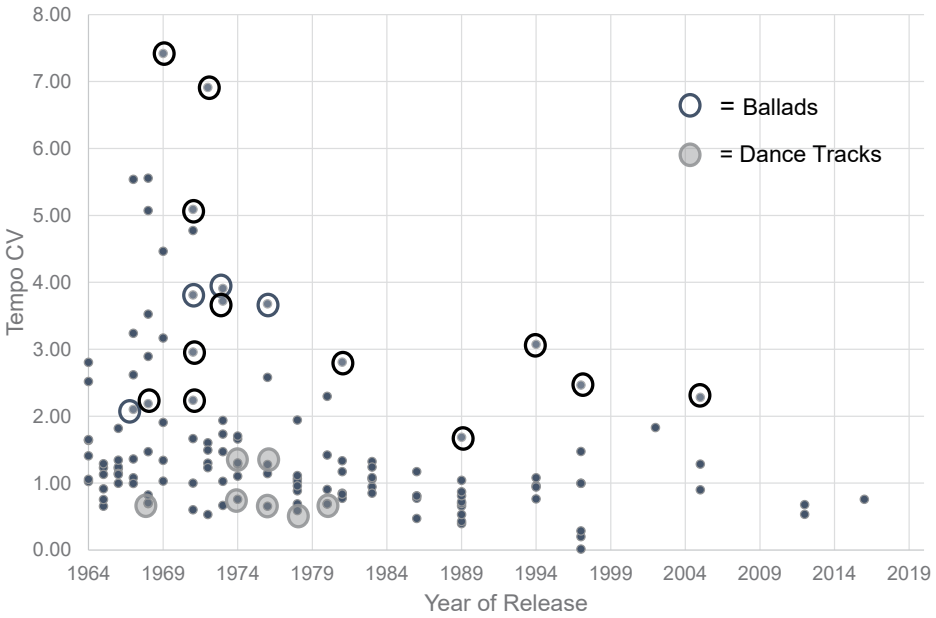
Example 31

The 13 Rolling Stones songs on which Charlie Watts played with the highest tempo CV measurements found for the band. Songs with substantial passages without drums or percussion are in gray on the list.

A third era for the Stones' approach to tempo variability began in 1974. Starting with their self-produced album *It's Only Rock 'n Roll*, the Stones returned to keeping the tempo steady throughout their songs, but now with increasingly metronomic precision. The Stones' median tempo CV returned to less than 1.3 in 1974 and remained under that upper limit for every analyzed year in the remainder of their career to date. Especially from 1980 onwards, the tempo CV in individual songs hardly ever rises above 1.0, with the only recordings over that threshold being slower ballads. Of the 59 Rolling Stones studio recordings with Watts released subsequent to 1976 that we analyzed, only one—the maudlin 1994 ballad "Out of Tears"—had a CV over 3.0. The increased steadiness of Stones tracks released after 1976 correlates with their greatly reduced use of backbeat delay in the same period.

In addition to identifying these three periods of the Stones' career, we noticed additional tendencies that apply to multiple eras. For instance, there appears to be a

relationship between tempo variability and genre, just as there is with microtiming. The band tended to keep a relatively steady tempo in their Caribbean-, funk-, and disco-influenced songs. Examples include "Hot Stuff" (CV of 0.66), "Hey Negrita" (1.28), "Sympathy for the Devil" (0.71), and "Miss You" (0.59) (Example 32). The Stones' ballads, on the other hand—such as "Memory Motel" (3.68), "Out of Tears" (3.07), and "Streets of Love" (2.28)—tended to significantly speed up and have relatively high CV values. This tendency in slower songs holds true throughout the Stones' career as well as in the songs of other artists prior to 1980. Songs and passages without drums or percussion (in gray in Example 31) also tended to have greater tempo variability, a tendency especially apparent between 1968 and 1973.



Example 32
Tempo CV for Rolling Stones ballads (high) and dance tracks (disco, funk, and Caribbean; low).

Looking at tempo variability in Stones live recordings, Watts and the band showed a tendency to accelerate when performing. All 23 tracks on their live album *El Mocambo 1977*, for example, speed up at least a little (Example 33). But overall, the Stones displayed a similar mean tempo variability in their live recordings as in their studio recordings. We performed tempo CV analyses on 23 Stones live recordings on which Watts played drums (Example 34), spanning 1969 to 2015, and compared the mean tempo CV of these recordings with that of the studio recordings of the same

songs. The mean CV was almost exactly the same, with the live versions having a mean of 2.01 and the studio versions of the same songs having a CV mean of 1.95 (p = .87). While many live versions displayed significantly more tempo variability than their studio counterparts (like "Tumbling Dice" and "Jumpin' Jack Flash"), the reverse was also true—the studio recordings of "You Can't Always Get What You Want," "Route 66," and "Monkey Man," for example, have much more tempo variability than the live versions we analyzed.

Song	Start BPM	End BPM	% Increase
Jumpin' Jack Flash	140	207	+48
Honky Tonk Women	99	120	+21
Little Red Rooster	56	66	+18
Melody	73	86	+18
Fool to Cry	68	78	+15
Star Star	145	166	+15
Worried Life Blues	68	78	+15
Worried About You	77	87	+13
Mannish Boy	61	69	+13
Brown Sugar	139	155	+12
Tumbling Dice	100	111	+11
Let's Spend the Night Together	147	161	+10
All Down the Line	151	165	+9
It's Only Rock 'n' Roll (But I Like It)	133	145	+9
Around and Around	185	201	+9
Hand of Fate	124	131	+6
Crazy Mama	112	119	+6
Rip This Joint	225	238	+6
Hot Stuff	107	112	+5
Dance Little Sister	150	158	+5
Crackin' Up	101	105	+4
Luxury	125	129	+3
Route 66	144	147	+2

Example 33

The 23 tracks on the Rolling Stones' 2022 live album *Live at the El Mocambo*, recorded in March 1977 in Toronto, ordered by greatest percentage increase in tempo from the start to the end of the song.

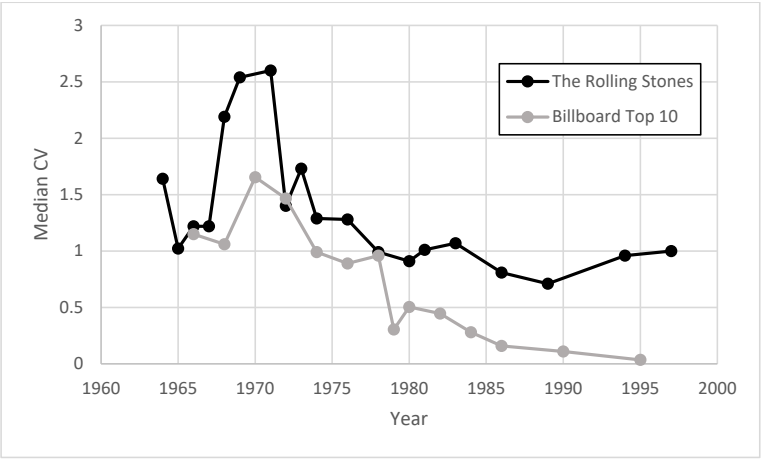
Year	Title	CV
1969	Live With Me (Get Yer Ya-Ya's Out!)	1.07
1976	Hot Stuff (Love You Live)	1.28
	Fingerprint File (Love You Live)	1.48
	Brown Sugar (Love You Live)	1.76
	You Can't Always Get What You Want (Love You Live)	3.12
	Tumbling Dice (Love You Live)	3.56
	Honky Tonk Women (Love You Live)	4.37
1977	Route 66 (Live at the El Mocambo)	0.80
	Star Star (Live at the El Mocambo)	2.99
1978	All Down the Line (Some Girls: Live in Texas '78)	1.28
	Jumping Jack Flash (Some Girls: Live in Texas '78)	1.99
	Star Star (Some Girls: Live in Texas '78)	2.04
	Honky Tonk Women (Some Girls: Live in Texas '78)	3.96
1995	The Spider and the Fly (Stripped)	1.97
2003	Monkey Man (Licked Live in NYC)	1.72
	Angie (Licked Live in NYC)	3.26
2004	Start Me Up (Live Licks)	1.08
2013	Start Me Up (Sweet Summer Sun)	0.89
	Emotional Rescue (Sweet Summer Sun)	1.02
	Honky Tonk Women (Sweet Summer Sun)	1.08
	Doom and Gloom (Sweet Summer Sun)	1.19
	Paint It, Black (Sweet Summer Sun)	1.36
2015	I Got the Blues (Live at the Fonda)	2.99
2023	Angry (Racket NYC)	0.65
	Shattered (Racket NYC)	0.97
	Tumbling Dice (Racket NYC)	1.77
	Jumping Jack Flash (Racket NYC)	1.03
	Whole Wide World (Racket NYC)	0.99
*Mean Live CV (*Watts songs only*): 2.01 (SD: 1.07)*		

Example 34

Tempo CV measurements for 28 Rolling Stones live tracks, ordered by year of recording. The five 2023 tracks were performed after Watts's death, with Steve Jordan on drums.

Comparing the Rolling Stones' tempo CV values in studio recordings with those of contemporaneous artists, Watts and the Stones overall showed substantially more tempo variability (mean CV = 1.62; 1964–2016) than the artists in the *Billboard* year-end Top 10 sample (mean CV = 0.89; 1966–2021; $p < .001$ for a two-sample *t*-test). The Stones' mean CV was slightly higher but in a similar range as that of the non-*Billboard* Others corpus, which had a mean of 1.48 (1935–2023; $p = .47$). Example 35 shows that the Stones' tempo CVs followed similar trends as the *Billboard* year-end Top 10 but

reflected significantly more tempo variability. In the 1967–71 and 1980–95 periods in particular, the Stones showed much more tempo variability than the *Billboard* sample. The year with the greatest tempo variability in the *Billboard* corpus is 1970, with songs such as "Ain't No Mountain High Enough," "Let It Be," and "I'll Be There" contributing to a median tempo CV of 1.65. Similarly, 1969 and 1971 are the two years with greatest tempo variability for the Stones (they released no studio recordings in 1970), but their median values of 2.54 and 2.60 in these years are significantly higher than the 1970 *Billboard* median of 1.65. The median CV for corpus Stones recordings released between 1967 and 1971 was 2.22, while the *Billboard* corpus median CV value for 1968–70 was 1.43. The 1967–71 period includes Stones ballads with extremely high tempo CV values like "You Got the Silver" (7.42), "Wild Horses" (5.09), and "Sister Morphine" (3.81).



Number of analyzed Stones songs per year, with standard deviations of CVs beneath:

Year	1964	1965	1966	1967	1968	1969	1971	1972	1973	1974
#	7	6	7	7	9	6	8	6	7	6
SD	0.69	1.02	0.26	1.61	1.86	2.42	1.69	2.35	1.27	0.35

Year	1976	1978	1980	1981	1983	1986	1989	1994	1997
#	5	8	5	6	6	5	10	5	7
SD	1.24	0.41	0.73	0.77	0.18	0.25	0.38	0.96	0.86

Example 35

Comparison of Rolling Stones tempo variability (overall mean CV = 1.62; songs on which Charlie Watts drummed only) with that of the year-end *Billboard* Top 10 (overall mean CV = 0.90) over time. Comparing the overall means of the two corpora (using a two-sample *t*-test), $p < .001$.

In the mid- to late 1970s both Rolling Stones and *Billboard* Top 10 tracks showed a decline in tempo variability as disco, funk, and reggae rose to prominence. Significantly, the Stones' 1978 album *Some Girls* (0.99) had almost the exact same median tempo variability as the *Billboard* Top 10 that year (0.96), with the Stones on the album following contemporary trends towards disco in "Miss You" (their last U.S. number-one single) and punk with tracks like "When the Whip Comes Down" and "Lies." But click tracks and drum machines rose to prominence in pop music in the late 1970s and early 1980s (Hesselink 2023, 124, 128–129), and the Stones for the most part did not follow suit. While the *Billboard* corpus median CV from 1979 on was 0.24, the Stones' median CV in the same time period was 0.90—significantly lower than the 1.34 it had been before 1979, yet much greater than that of the *Billboard* Top 10 and well outside the range suggesting use of a click track.[34] It thus appears from the data that the Stones largely continued recording without a click even as click tracks, sequencing, and drum machines dominated the popular mainstream in the 1980s and '90s. While the band with their 1986, 1989, and 1997 albums (*Dirty Work*, *Steel Wheels*, and *Bridges to Babylon*) showed a tendency towards lesser tempo variability as they tried out more modern approaches to recording and worked with hip-hop producers the Dust Brothers, among others, their CV numbers even in this period are not nearly as low as mainstream pop acts of the time. Example 36 shows their six songs with tempo CV values less than 0.5, all from these three albums.[35] Since 1997, the Stones seem to have largely rejected the use of tempo assistance in recording, with their tempo CVs primarily ranging between 0.5 and 2.0. Nowadays, even with Steve Jordan having taken the late Watts's place, critics notice the band's flexible tempos as something rare in popular music, with *New York Times* critic Jon Pareles writing of the band's 2023 *Hackney Diamonds* album: "The songs are unapologetically hand-played and organic, not quantized onto a computer grid; they speed up and slow down with a human pulse" (2023).

VI. Conclusion

Questions regarding whether Charlie Watts's delayed backbeats had patterns of tempo variability or had a special "feel" that made him an outstanding drummer and a key contributor to the Rolling Stones' sound have broader resonance for the analysis of

34 Songs in our *Billboard* and non-*Billboard* Others corpora known to have been recorded to a click track typically have CV values ranging between 0.2 and 0.5: for instance, Nirvana's "Lithium," 0.20 (Coffman 2023); Sly & the Family Stone's "Family Affair," 0.27 (LeRoy 2023, 32); and Ron Wood's "Shirley," 0.39 (LeRoy 2023, 38).

35 The low tempo CV measurements for the Stones tracks in Example 36 suggest the use of mechanical assistance, despite guitarist Keith Richards's vocal disapproval of the use of "hi-tech stuff" in the studio (Mattingly 1990, 21). For 1997's "Saint of Me," one of three Dust Brothers-produced tracks in Example 36, Watts played over a recording of a Roland TR-808 drum machine (Janovitz 2013, 363–364).

CV	Title	Year	Album
0.01	Anybody Seen My Baby	1997	*Bridges to Babylon*
0.20	Might as Well Get Juiced	1997	*Bridges to Babylon*
0.29	Saint of Me	1997	*Bridges to Babylon*
0.39	Terrifying	1989	*Steel Wheels*
0.43	Sad Sad Sad	1989	*Steel Wheels*
0.47	Harlem Shuffle	1986	*Dirty Work*

Example 36
The six analyzed Rolling Stones songs with a tempo CV of less than 0.5.

music and how listeners mythologize musicians. Our findings suggest that there is some truth to the notion that Watts did subtle things in his drumming that had a significant impact on the sound of the band, but the extent to which these elements made him unique may have been exaggerated. Our study examining a corpus of 81 Rolling Stones recordings and 59 recordings by other artists suggests that Watts delayed backbeats more often than his contemporaries, particularly between 1967 and 1973, when he substantially delayed 45 percent of his second beats. Prior to 1979, Watts substantially delayed 33 percent of his second beats, while other drummers studied delayed only 20 percent. Over the entirety of his career, Watts delayed beat 4 approximately the same amount as beat 2, while other drummers showed no significant tendency to delay beat 4. With respect to tempo variability, we found four recurring patterns of tempo change within Rolling Stones songs. We also determined that while the Stones largely followed mainstream pop's trends with regard to tempo variability over time, the band tended to accelerate and have greater tempo variability than mainstream pop, particularly in the 1967–71 and 1980–95 periods. The band's median tempo coefficient of variation between 1967 and 1971 was 2.22, while the *Billboard* corpus median CV value for 1968–70 was 1.43. And from 1979 on, the Stones' median CV was 0.90, while the *Billboard* corpus median was 0.24.

Backbeat delay and tempo variability are particularly associated with the genres embraced by the band between 1968 and 1973, a time when they were produced by Jimmy Miller and their music drew heavily from blues, R&B, soul, gospel, Americana, and country. It is therefore not surprising that this was the time in which we found the most significant evidence of backbeat delay and tempo variability. This era is often cited as the Stones' "golden era," when their recordings were most consistently successful from an artistic and commercial point of view, and part of this success may derive

from their microtiming and tempo approaches. Despite dalliances with metronomic technology in the 1980s and '90s, the Stones today can be heard as representatives of an earlier approach to tempo variability that had mostly disappeared from the popular mainstream by the twenty-first century.

It is important to note that, while Watts delayed backbeats in numerous songs, there are many recordings in which he did not use this approach, even during the time period when we found the most delayed backbeats. It is not clear whether Watts consciously changed his approach from song to song based on musical factors, whether changes in approach occurred accidentally, or some combination of these. It is also not clear to what extent backbeat delay or tempo variability on the scale we observed plays an important role in the "feel" or success of a track. The "feel" or "signature" of an individual drummer is the result of many factors besides microtiming and tempo variability, including the specific drumming equipment used and alterations to it, how the drums were recorded, dynamics, and the choice of drum patterns and fills. In addition, Watts's playing occurred within the complex context of a five-person band (occasionally with additional musicians), and his contributions ultimately must be considered as part of that whole rather than in isolation. Given these factors, it is reasonable to suppose that many of the references to "delayed backbeats" and "playing in the pocket" that we encounter in tributes to Charlie Watts are a romanticization of an earlier generation of musicians and a distrust of technology. The Stones' Keith Richards himself has lauded Watts's ability to "innately" push and pull the tempo as an antidote to more modern recording practices: "It's a bit of expression, instead of people looking at numbers and readouts. That doesn't constitute rhythm; that just constitutes timing" (Mattingly 1990, 21).

Our research thus contributes to the conversation about "humanity" versus "automation" in music, both in the past and the present. The fact that Rolling Stones fans continue to vigorously debate in online forums whether the band has used click tracks shows the importance of these questions among listeners who view the Stones as icons of spontaneity and rebellion. By using objective methods to measure microtiming and tempo variability, we show that these discussions need not remain an echo chamber of competing rumors. Determining whether microtiming or tempo deviations have occurred will not end the debate over their value, but will allow listeners to better draw their own, more informed conclusions and listen to popular music with increased sensitivity to rhythmic nuance.

We are grateful for the work of our research assistants Mira Perusich, Jonas Kastenhuber, Alexis Cantelme, and Monserrat Torres Guillen, as well as for the feedback of Trevor de Clercq and the anonymous peer reviewers.

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Appendix Examples

Appendix Example 1: Microtiming in 62 Rolling Stones studio recordings, ordered by year of release. The beat 2 and beat 4 "JND Early" and "JND Late" percentages refer to the frequency of deviations of 2.5 percent of the average IOI or larger. "Bt. 2 % of IOI" translates the raw beat 2 delay into a percentage of the mean IOI for the song. The *p*-values for beat deviation means are the result of two-sided one-sample *t*-tests with a null hypothesis of a mean of zero. Red highlighting indicates beat 2 or 4 JND Early or Late percentages of 40 percent or greater; "*n*" refers to the number of second beat attacks analyzed for each song. *The summary statistics at the bottom of the chart incorporate "Emotional Rescue" as a single song.

Appendix Example 2: Microtiming in other drummers (59 recordings), ordered by year of release of recording. The beat 2 and beat 4 "JND Early" and "JND Late" percentages refer to the frequency of deviations of 2.5 percent of the average IOI or larger. "Bt. 2 % of IOI" translates the raw beat 2 delay into a percentage of the mean IOI for the song. The *p*-values for beat deviation means are the result of two-sided one-sample *t*-tests with a null hypothesis of a mean of zero. Red highlighting indicates beat 2 or 4 JND Early or Late percentages of 40 percent or greater; "*n*" refers to the number of second beat attacks analyzed for each song. Three Rolling Stones songs with drummers other than Charlie Watts were also included.

Appendix Example 3: The 133 Rolling Stones studio recordings with Charlie Watts that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV). Calculations exclude closing ritardandi, and songs in compound meter were analyzed in 12/8. Red shading indicates a tempo CV of 3.0 or higher, indicating great tempo variability; yellow shading indicates a tempo CV of less than 0.5, suggesting the use of a click track, drum machine, or looped sample. *"Salt of the Earth" switches to a double-time feel in the outro; the tempo CV was calculated treating that portion as if the tactus had not changed.

Appendix Example 4: The 150 songs from year-end Billboard Top 10 rankings that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV). Songs in compound meter have been analyzed in 12/8. Ending ritardandi are excluded from calculations.

Appendix Example 5: 154 additional songs by other artists analyzed for tempo variability (CV). Songs in compound meter have been analyzed in 12/8. The table includes Rolling Stones songs on which Charlie Watts did not play drums. Closing ritardandi are excluded from calculations. *"You Can't Always Get What You Want" switches to a double-time feel at the end of the outro; the tempo CV was calculated treating that portion as if the tactus had not changed.

Song Title	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
			Bt. 2 JND Early %	Bt. 2 JND Late %	Bt. 4 JND Early %	Bt. 4 JND Late %	Bt. 1 *M*	Bt.2 *M*	Bt. 2 *SD*	Bt 2 *t*	Bt. 2 *p*	Bt. 2 % of IOI	Bt. 3 *M*	Bt. 4 *M*	Bt. 4 % of IOI		
Heart of Stone	1964	63	3	25	20	29	-8	**14**	23	3.61	<0.001	1.5	7	8	0.9	full song	36
I'm a King Bee	1964	105	0	50	6	51	-1	**14**	10	10.90	<0.001	2.4	0	**14**	2.5	full song	64
Poison Ivy ("Version 1" from *More Hot Rocks*)	1964	146	11	11	22	32	-2	1	9	0.79	0.43	0.2	-1	2	0.3	full song	70
Mercy, Mercy	1965	125	19	26	26	52	1	4	16	1.36	0.19	0.9	5	9	1.9	0:06-1:07	27
Out of Time (marimba version)	1966	127	18	24	41	28	0	0	17	0.04	0.97	0.0	4	-2	-0.5	0:15-1:18	33
2000 Light Years from Home	1967	123	7	73	16	62	-3	**23**	19	8.88	<0.001	4.8	0	**18**	3.7	0:54-2:45	55
She's a Rainbow	1967	108	0	39	17	33	-5	**9**	11	3.38	0.004	1.6	0	3	0.5	0:40-1:05, 1:22-1:47	18
Salt of the Earth	1968	94	16	53	30	40	5	**20**	37	2.47	0.02	3.5	21	25	3.9	1:21-2:16	19
Jigsaw Puzzle	1968	107	5	49	28	41	-4	**15**	21	5.55	<0.001	2.8	6	8	1.5	0:54-2:45	61
Monkey Man	1969	103	0	87	19	35	-4	**28**	13	20.27	<0.001	4.7	5	**9**	1.8	0:21-4:00	93
Let It Bleed	1969	114	3	55	18	40	-2	**14**	16	6.68	<0.001	2.7	1	**8**	1.6	0:08-2:17	58
Gimme Shelter	1969	117	0	48	15	41	-1	**13**	14	5.48	<0.001	2.5	0	**8**	1.5	0:41-2:00	40
Sister Morphine	1971	94	3	56	24	38	-4	**20**	20	6.28	<0.001	3.1	9	9	1.5	2:37-5:00	39
Wild Horses	1971	73	7	64	16	50	-13	**27**	27	6.67	<0.001	3.3	8	**23**	2.6	full song	45
I Got the Blues	1971	40	3	30	14	38	-13	9	37	1.29	0.21	0.6	0	6	0.5	0:26-3:26	30
Dead Flowers	1971	130	10	27	20	31	-1	**4**	12	3.64	<0.001	0.9	1	2	0.4	0:00-3:51	124
Sway	1971	70	0	28	22	28	1	**13**	16	3.58	0.002	1.6	9	8	1.0	0:07-1:11	18

Appendix Example 1
Microtiming in 62 Rolling Stones studio recordings, ordered by year of release.

Song Title	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
Loving Cup	1972	78	0	44	18	45	-3	**19**	13	8.51	<0.001	2.5	6	**14**	1.8	0:54-1:44 2:24-3:00 3:11-3:40	34
Ventilator Blues	1972	67	0	51	11	28	-2	**23**	16	10.17	<0.001	2.6	6	**18**	1.3	full song	47
Let It Loose	1972	78	5	45	18	47	-7	**21**	27	4.64	<0.001	2.6	8	**17**	2.2	0:00-3:14	42
Torn and Frayed	1972	89	0	41	17	23	-5	**15**	15	5.55	<0.001	2.2	7	6	0.8	0:06-1:30	29
Tumbling Dice	1972	111	4	46	17	48	-2	**12**	15	5.82	<0.001	2.2	7	**14**	2.7	0:02-2:21	57
Rocks Off	1972	142	0	48	6	51	0	**13**	12	8.94	<0.001	3.0	0	**15**	3.5	0:00-2:03	71
All Down the Line	1972	140	3	32	8	54	0	**9**	10	5.43	<0.001	2.1	-2	**15**	3.5	0:07-1:12	37
Casino Boogie	1972	118	19	23	34	26	-2	2	19	0.77	0.45	0.4	-1	1	0.4	0:34-2:40	79
Sweet Virginia	1972	108	8	16	34	21	-2	3	14	1.97	0.05	0.6	1	-1	-0.3	0:48-4:12	91
Angie	1973	70	14	45	15	46	-4	**16**	31	4.05	<0.001	1.9	11	12	1.5	0:47-4:25	62
Through the Lonely Nights	1974	80	0	31	38	38	-20	**14**	18	2.79	0.02	1.8	8	0	0.1	0:06-0:48	13
Fingerprint File	1974	102	8	29	16	43	1	**9**	17	3.78	<0.001	1.6	15	**13**	2.1	0:00-2:20	51
Time Waits for No One	1974	118	10	37	20	41	-1	**6**	13	3.83	<0.001	1.2	3	7	1.5	0:20-2:50	70
If You Can't Rock Me	1974	125	51	6	14	22	-1	**-10**	13	6.41	<0.001	-2.1	-2	2	0.5	0:00-2:20	72
Memory Motel	1976	85	7	19	22	32	-2	4	16	1.48	0.15	0.5	7	2	0.4	1:13-2:00, 3:08-4:22	42
Crazy Mama	1976	109	17	9	22	22	-5	-2	12	0.96	0.35	-0.4	-4	-5	-0.9	0:09-1:02	23
Hand of Fate	1976	115	7	13	21	21	-5	0.4	16	0.11	0.91	0.1	3	1	0.2	0:01-0:32	15
Hot Stuff	1976	100	45	0	19	19	1	**-15**	9	7.96	<0.001	-2.5	-17	-1	-0.2	0:04-0:58	22
Beast of Burden	1978	101	0	32	18	46	-5	**10**	13	3.98	<0.001	1.6	4	11	1.9	0:19-0:56	28

Appendix Example 1 (continued)
Microtiming in 62 Rolling Stones studio recordings, ordered by year of release.

Song Title	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
Some Girls	1978	72	7	20	21	21	-6	2	19	0.49	0.63	0.3	-1	2	0.3	0:12-0:35, 0:52-1:23	15
Far Away Eyes	1978	94	10	14	33	29	-6	2	15	0.72	0.48	0.4	-2	0	0.1	0:00-0:57	21
Miss You	1978	110	7	15	25	32	-1	**3**	11	2.36	0.02	0.6	1	2	0.5	0:00-2:13	59
When the Whip Comes Down	1978	130	15	22	37	30	-2	2	11	0.96	0.35	0.5	4	2	0.5	0:00-0:52	27
Lies	1978	162	21	21	33	27	0	1	14	0.31	0.76	0.2	6	3	0.7	0:00-1:20	53
Before They Make Me Run	1978	132	19	23	31	42	1	0	13	0.02	0.99	0.0	8	5	1.1	0:03-0:52	26
Respectable	1978	153	35	6	35	26	-2	**-7**	12	3.14	0.004	-1.7	3	-2	-0.5	0:03-0:53	31
Emotional Rescue* (4 on the floor)	1980	111	16	6	27	29	0	-4	13	2.38	0.02	-0.8	-3	1	0.2	0:00-1:18; 1:56-2:11; 3:18-3:29; 3:51-4:06	49
Emotional Rescue (backbeat)	1980	115	10	16	25	25	-3	1	13	0.92	0.36	0.2	1	1	0.3	1:18-1:56; 2:11-3:18; 3:29-3:51; 4:06-5:23	103
All About You	1980	86	11	18	30	25	-3	3	18	0.98	0.33	0.4	1	2	0.3	0:12-2:24	44
No Use in Crying	1981	48	3	24	14	43	6	**12**	23	3.11	0.004	1.0	-7	**17**	1.4	full song	37
Start Me Up	1981	123	19	4	36	24	-2	-4	9	2.07	0.05	-0.8	-5	-7	-1.5	0:00-0:52	26
Had It with You	1986	169	7	30	25	34	0	**4**	9	3.53	<0.001	1.2	1	4	1.0	0:04-1:42	67
Harlem Shuffle	1986	121	4	15	19	26	-2	2	9	1.27	0.22	0.4	4	0	0.0	0:01-0:56	27
Blinded by Love	1989	111	13	13	23	23	-1	0	12	0.01	0.996	0.0	-5	1	0.1	0:00-1:09	31
Almost Hear You Sigh	1989	102	19	11	31	26	-1	0	15	0.06	0.96	-0.2	1	0	-0.1	0:00-2:30	36
Mixed Emotions	1989	137	10	3	30	23	-1	-3	10	1.50	0.15	-0.6	-1	-2	-0.5	0:00-0:56	31
Out of Tears	1994	73	5	24	39	31	-8	6	26	1.49	0.145	0.8	0	1	0.2	0:41-2:54	36
Love Is Strong	1994	109	12	19	12	24	-1	5	13	1.90	0.07	0.9	0	5	1.0	0:00-1:00	26

Appendix Example 1 (continued)

Microtiming in 62 Rolling Stones studio recordings, ordered by year of release.

Song Title	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
Brand New Car	1994	118	43	11	46	21	-1	**-7**	16	2.36	0.03	-1.4	1	-10	-2.0	0:00-1:00	28
You Got Me Rocking	1994	126	16	10	30	20	0	-3	12	1.20	0.24	-0.5	0	-2	-0.4	0:00-1:00	31
Already Over Me	1997	75	2	42	25	39	-3	**15**	17	6.80	<0.001	1.9	0	4	0.5	0:40-3:45	57
Don't Stop	2002	125	0	8	17	43	-3	4	10	1.87	0.08	0.8	1	5	1.1	0:00-0:47	24
Oh No Not You Again	2005	141	3	49	16	51	0	**10**	9	6.62	<0.001	2.4	3	**8**	2.0	0:01-1:08	37
One More Shot	2012	123	2	55	8	56	0	**16**	16	7.08	<0.001	3.4	7	**19**	3.9	0:08-1:46	51
Commit a Crime	2016	125	31	14	34	31	-1	-6	18	1.82	0.08	-1.3	0	-2	-0.4	0:00-0:58	29
Living in a Ghost Town	2020	111	8	29	13	37	0	**8**	16	2.8	0.007	1.4	3	**10**	1.9	0:00-1:27	38
Mean	1978.9	108	10.3	29.4	22.7	34.7	-2.5	7.1	15.9	3.8		1.1	2.5	5.9	1.0		44
Standard Deviation	12.7	26.7	11.3	18.5	9.1	10.8	3.9	9.2	6.2	3.5		1.5	5.4	7.3	1.3		26
Median	1975	111	7	26	21	32	-2	6	15	3		0.9	1	5	0.8		37
Minimum	1964	40	0	0	6	19	-20	-15	9	0	<0.001	-2.5	-17	-10	-2		13
Maximum	2020	169	51	87	46	62	6	28	37	20	0.996	4.8	21	25	3.9		152

Appendix Example 1 (end)

Microtiming in 62 Rolling Stones studio recordings, ordered by year of release.

Song Title	Artist	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
				Bt. 2 JND Early %	Bt. 2 JND Late %	Bt. 4 JND Early %	Bt. 4 JND Late %	Bt. 1 *M*	Bt. 2 *M*	Bt. 2 *SD*	Bt. 2 *t*	Bt. 2 *p*	Bt. 2 % of IOI	Bt. 3 *M*	Bt. 4 *M*	Bt. 4 % of IOI		
I'm a King Bee	Slim Harpo	1957	112	9	14	24	22	-2	0	11	0.28	0.78	-0.1	0	-2	-0.3	full song	80
Green Onions	Booker T. & The MGs	1962	137	2	46	8	15	0	**10**	7	13.63	<.001	2.4	2	1	0.2	full song	89
Mr. Pitiful	Otis Redding	1964	125	6	17	37	11	-1	4	10	1.61	0.13	0.8	2	-6	-1.2	0:02-0:40	18
Dancing in the Street	Martha & the Vandellas	1964	127	11	23	37	31	-2	**3**	14	2.04	0.045	0.8	-1	2	0.4	0:02-2:20	70
Heart of Stone **(Metamorphosis)**	The Rolling Stones (Cattini on drums)	1964	59	10	0	29	19	-1	-6	14	2.02	0.08	-0.6	-4	-5	-0.4	0:00-1:45	21
Nowhere Man	The Beatles	1965	121	3	9	12	34	1	2	11	1.55	0.12	0.4	4	**7**	1.5	full song	70
In the Midnight Hour	Wilson Pickett	1965	112	5	9	26	12	0	1	9	0.69	0.49	0.2	8	**-6**	-1.1	0:01-2:19	58
Hey Joe	The Jimi Hendrix Experience	1966	83	7	37	23	27	-6	**13**	24	3.04	0.005	1.9	12	20	2.0	0:08-1:38	30
Hold On, I'm Comin'	Sam & Dave	1966	108	0	19	5	34	-1	**9**	7	10.11	<.001	1.7	2	**8**	1.5	full song	64
Knock on Wood	Eddie Floyd	1966	104	0	6	17	22	-1	1	9	0.49	0.63	0.2	5	2	0.4	0:00-0:44	18
And Your Bird Can Sing	The Beatles	1966	133	11	61	16	50	0	**12**	15	6.08	<.001	2.6	8	**7**	1.5	0:00-0:54	62
Soul Man	Sam & Dave	1967	113	6	0	21	9	0	-1	8	1.04	0.31	-0.3	-4	-4	-0.7	0:00-1:26	35
Caledonia Mission	The Band	1968	61	3	21	19	36	4	**12**	26	2.70	0.009	1.2	14	18	1.9	full song	38
I'm So Tired	The Beatles	1968	71	7	7	43	20	-25	-5	15	1.82	0.08	-0.6	-7	-14	-1.6	full song	30
You Shook Me	Led Zeppelin	1969	52	0	11	16	29	8	**9**	17	3.26	0.002	0.8	12	**11**	1.0	0:00-3:05	38
I Can't Quit You Baby	Led Zeppelin	1969	54	0	30	11	42	2	**17**	20	3.71	0.001	1.5	13	19	1.8	0:00-1:32	20

Appendix Example 2

Microtiming in other drummers (59 recordings), ordered by year of release of recording.

Song Title	Artist	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
Heartbreaker	Led Zeppelin	1969	97	9	18	45	10	-3	-2	14	0.69	0.50	-0.3	1	**-12**	-2.0	0:06-0:26; 0:49-1:24	22
The Weight (live)	Joe Cocker	1970	75	0	55	19	38	-6	**20**	21	4.43	<.001	2.4	6	10	1.3	0:00-1:24	22
Funky Drummer	James Brown	1970	101	0	63	13	13	1	**18**	6	8.45	<.001	3.0	12	0	-0.1	famous 8 bars	8
Have You Ever Seen the Rain?	Creedence Clearwater Revival	1970	116	7	16	21	19	0	2	12	1.23	0.22	0.4	4	0	0.1	0:00- 3:03	73
Imagine	John Lennon	1971	76	10	17	32	20	0	4	17	1.24	0.19	0.4	-4	-9	-1.0	0:39-2:52	42
Family Affair	Sly & the Family Stone	1971	109	18	17	36	24	0	0	16	0.01	0.99	0.0	8	-4	-0.6	full song	76
It Ain't No Fun to Me	Al Green	1972	87	0	6	0	19	-3	**9**	7	5.03	<.001	1.3	2	7	1.0	0:00-0:47	16
I Never Found a Girl	Al Green	1972	94	0	5	26	16	-5	0	8	0.05	0.96	0.0	-2	-4	-0.6	0:00-0:53	20
Could It Be I'm Falling in Love	The Spinners	1972	103	11	0	38	2	-3	**-5**	8	5.14	<.001	-0.9	-7	**-9**	-1.6	0:00-2:14	56
Kashmir	Led Zeppelin	1975	81	13	9	17	17	-1	-3	13	1.28	0.21	-0.5	1	-5	-0.6	0:00-1:11	23
53rd & 3rd	Ramones	1976	135	30	34	41	45	-3	4	21	1.12	0.27	0.8	5	4	1.1	0:00-1:20	44
Tumbling Dice	Linda Ronstadt	1977	110	8	28	32	32	0	5	12	1.90	0.07	0.9	7	2	0.4	0:00-0:59	25
Hell Ain't a Bad Place To Be	AC/DC	1977	128	25	0	29	17	-2	**-5**	10	2.45	0.02	-1.1	1	-6	-1.2	0:34-1:19	24
Dreams	Fleetwood Mac	1977	120	16	9	32	22	0	**-3**	10	3.14	0.002	-0.6	2	-2	-0.4	0:00-3:21	93
Easy	Commodores	1977	66	0	46	19	42	4	**17**	19	4.46	<.001	1.8	4	13	1.4	0:15-2:30	26
Stayin' Alive	Bee Gees	1977	104	0	0	14	0	0	-1	5	1.04	0.32	-0.2	-2	-3	-0.6	0:00-0:35	15
Take Me to The River	Talking Heads	1978	99	0	35	16	42	-2	**12**	8	6.31	<.001	1.9	-3	8	1.4	0:00-0:51	20

Appendix Example 2 (continued)
Microtiming in other drummers (59 recordings), ordered by year of release of recording.

Song Title	Artist	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
One Way or Another	Blondie	1978	163	29	29	43	26	0	2	13	0.76	0.45	0.6	8	-3	-0.7	0:11-0:47	24
Da Ya Think I'm Sexy	Rod Stewart	1978	112	18	5	40	15	-1	**-5**	12	2.90	0.005	-0.8	3	-5	-0.9	0:00-2:02	55
Can't Stand Losing You	The Police	1978	144	16	9	30	14	0	**-3**	11	2.27	0.03	-0.7	1	-4	-1.0	1:04-2:55	64
Fool in the Rain	Led Zeppelin	1979	65	3	13	23	26	0	1	16	0.25	0.80	0.1	3	2	0.2	0:00-1:58	31
De Do Do Do, De Da Da Da	The Police	1980	147	18	7	26	14	0	**-2**	8	2.97	0.004	-0.5	2	-2	-0.4	full song	121
Refugee	Tom Petty	1980	116	20	24	43	36	0	0	16	0.21	0.83	0.1	4	0	0.1	0:00-3:14	93
The River	Bruce Springsteen	1980	118	53	6	46	18	-1	**-10**	15	5.02	<.001	-2.0	1	-5	-1.0	3:00-4:50	51
Physical	Olivia Newton-John	1981	124	0	1	0	3	0	**2**	5	4.07	<.001	0.6	0	1	0.1	0:00-2:24	74
Stop Draggin' My Heart Around	Stevie Nicks/ Tom Petty	1981	107	0	11	28	28	-1	4	9	1.76	0.09	0.7	5	2	0.4	0:09-0:57	19
1999	Prince	1982	119	0	0	0	0	0	**9**	1	102.45	<.001	1.7	0	**9**	1.7	0:35-3:43	91
Every Breath You Take	The Police	1983	116	76	0	63	4	0	**-20**	11	12.02	<.001	-3.8	4	**-18**	-3.4	0:00-1:48	49
Romeo Had Juliette	Lou Reed	1989	131	38	29	38	29	1	-4	26	0.82	0.42	-0.9	5	-2	-0.3	0:14-1:00	24
Enter Sandman	Metallica	1991	125	18	14	29	14	-5	1	14	0.26	0.80	0.2	1	-4	-0.7	0:55-2:39	28
Evening Gown	Mick Jagger	1993	78	2	21	20	31	-2	**8**	13	4.42	<.001	1.0	7	5	0.7	full song	61
If It Makes You Happy	Sheryl Crow	1996	95	0	6	6	12	-2	4	9	1.72	0.10	0.6	0	3	0.4	0:00-0:47	17
My Heart Will Go On	Celine Dion	1997	49	0	0	0	0	0	**-2**	1	4.02	0.01	-0.2	0	**-2**	-0.2	3:24-4:03	7
Conant Gardens	Slum Village (J. Dilla)	2000	94	0	0	0	0	0	**-14**	1	107.60	<.001	-2.2	2	**-14**	-2.2	0:12-1:14	24

Appendix Example 2 (continued)

Microtiming in other drummers (59 recordings), ordered by year of release of recording.

Song Title	Artist	Year	Mean Tempo	Accumulated, Previous				Accumulated Deviation, Relative to Previous (Means in ms)									Portion Analyzed	*n*
The Root	D'Angelo	2000	80	2	0	14	0	0	**-11**	3	28.57	<.001	-1.5	0	**-11**	-1.5	0:00-2:37	52
The Line	D'Angelo	2000	80	63	0	8	0	0	**-23**	5	29.73	<.001	-3.1	4	**-14**	-1.8	0:06-2:15	40
Angel	Shaggy	2001	85	0	0	0	0	0	**-1**	1	4.78	<.001	-0.2	1	-1	-0.1	0:01-0:59	20
Shake Shake Mama	Bob Dylan	2009	80	0	0	18	24	2	2	9	0.57	0.58	0.2	1	3	0.5	0:00-0:56	18
This Forgotten Town	The Jayhawks	2020	79	5	33	21	34	-4	**13**	19	4.35	<.001	1.8	7	5	0.7	0:05-2:05	39
All Down the Line	Blackberry Smoke	2022	138	29	18	41	26	0	-1	11	0.44	0.66	-0.2	-1	-2	-0.4	0:00-0:59	28
Paint the Red Rose Blue	Elvis Costello	2022	60	0	0	0	0	0	**-11**	7	9.06	<.001	-0.9	-1	**-12**	-1.0	0:00-0:38	44
Driving Me Too Hard	The Rolling Stones (Jordan on drums)	2023	106	9	8	35	25	-1	-2	11	1.71	0.09	-0.4	4	-2	-0.2	full song	79
Angry	The Rolling Stones (Jordan on drums)	2023	113	11	0	22	15	0	**-5**	7	5.61	<.001	-1.0	3	**-4**	-0.7	0:00-2:08	57
Mean		1980.7	101.6	10.8	15.3	23.2	20.1	-1.0	1.4	11.5	7.5		0.2	2.8	-0.5	-0.1		43.3
Standard Deviation		16.9	26.4	15.5	16.1	14.4	13.1	3.9	8.6	5.9	19.3		1.3	4.6	8.1	1.1		26.0
Median		1977	106	6	9	22	19	0	1	11	2.5		0.2	2	-2	-0.2		38
Minimum		1957	49	0	0	0	0	-25	-23	1	0	<.001	-3.8	-7	-18	-3.4		7
Maximum		2023	163	76	63	63	50	8	20	26	107.6	0.99	3	14	20	2		121

Appendix Example 2 (end)

Microtiming in other drummers (59 recordings), ordered by year of release of recording.

Year	Title	Mean Tempo	CV
1964	Tell Me	122	2.80
1964	You Can Make It If You Try	68	1.64
1964	Around and Around	183	1.41
1964	It's All Over Now	197	1.06
1964	Little by Little	175	2.52
1964	I'm a King Bee	105	1.03
1964	Route 66	170	1.65
1965	Off the Hook	153	0.65
1965	Satisfaction	136	0.76
1965	The Last Time	168	1.23
1965	Get Off of My Cloud	126	1.13
1965	Mercy Mercy	124	0.92
1965	The Spider and the Fly	99	1.29
1966	Out of Time (Strings Version)	127	1.00
1966	Out of Time (Marimba Version)	127	1.22
1966	Mother's Little Helper	204	1.24
1966	19th Nervous Breakdown	193	1.15
1966	Under My Thumb	127	1.13
1966	Have You Seen Your Mother…	202	1.82
1966	Paint It, Black	159	1.34
1967	She Smiled Sweetly	65	2.10
1967	Let's Spend the Night Together	141	1.08
1967	Miss Amanda Jones	158	1.36

Year	Title	Mean Tempo	CV
1967	Ruby Tuesday	107	1.00
1967	We Love You	107	5.54
1967	The Lantern	98	2.62
1967	Citadel	116	3.24
1968	Jumpin' Jack Flash	137	0.69
1968	Factory Girl	113	5.07
1968	Sympathy for the Devil	116	0.71
1968	Street Fighting Man	126	0.82
1968	Jigsaw Puzzle	110	2.89
1968	Dear Doctor	122	1.47
1968	Salt of the Earth*	94	5.56
1968	No Expectations	90	2.19
1968	Stray Cat Blues	104	3.52
1969	Honky Tonk Women	121	3.49
1969	Monkey Man	102	4.46
1969	Gimme Shelter	118	1.03
1969	Country Honk	121	1.91
1969	You Got the Silver	94	7.42
1969	Live With Me	130	1.34
1971	I Got the Blues	40	2.96
1971	You Gotta Move	68	4.78
1971	Wild Horses	71	5.09
1971	Sister Morphine	92	3.81

Appendix Example 3

The 133 Rolling Stones studio recordings with Charlie Watts that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV).

Year	Title	Mean Tempo	CV
1971	Moonlight Mile	65	2.24
1971	Bitch	136	0.61
1971	Brown Sugar	128	1.00
1971	Sway	72	1.66
1972	Rocks Off	142	1.30
1972	Torn and Frayed	90	1.60
1972	Stop Breaking Down	105	1.23
1972	Sweet Virginia	104	6.91
1972	Tumbling Dice	111	1.50
1972	All Down the Line	140	0.58
1973	Angie	69	3.72
1973	Star Star	142	1.03
1973	Silver Train	147	0.67
1973	Dancing with Mr. D	106	1.47
1973	Doo Doo Doo…(Heartbreaker)	111	1.94
1973	Coming Down Again	71	3.91
1973	Hide Your Love	110	1.73
1974	Time Waits for No One	119	1.28
1974	If You Can't Rock Me	126	1.30
1974	Ain't Too Proud to Beg	128	1.66
1974	Fingerprint File	104	1.70
1974	Luxury	129	0.76
1974	Dance Little Sister	153	1.10

Year	Title	Mean Tempo	CV
1976	Memory Motel	85	3.68
1976	Hand of Fate	117	1.14
1976	Hot Stuff	100	0.66
1976	Hey Negrita	85	1.28
1976	Crazy Mama	113	2.58
1978	Just My Imagination	114	1.94
1978	When the Whip Comes Down	131	1.07
1978	Lies	163	0.69
1978	Miss You	110	0.59
1978	Some Girls	73	1.11
1978	Beast of Burden	101	1.02
1978	Respectable	152	0.89
1978	Shattered	140	0.96
1980	Emotional Rescue	114	2.30
1980	Down in the Hole	62	1.42
1980	Dance (Pt. 1)	107	0.69
1980	Send It to Me	94	0.69
1980	Let Me Go	148	0.91
1981	Start Me Up	123	0.77
1981	No Use in Crying	48	1.17
1981	Worried About You	85	2.81
1981	Slave	67	1.33
1981	Hang Fire	153	0.84

Appendix Example 3 (continued)

The 133 Rolling Stones studio recordings with Charlie Watts that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV).

Year	Title	Mean Tempo	CV
1981	Black Limousine	109	0.85
1983	All the Way Down	143	1.32
1983	Tie You Up	117	0.95
1983	Wanna Hold You	156	1.24
1983	Undercover of the Night	123	1.08
1983	She Was Hot	152	0.85
1983	Feel on Baby	131	1.06
1986	Had It with You	170	1.17
1986	Harlem Shuffle	122	0.47
1986	Fight	158	0.77
1986	Hold Back	144	0.81
1986	One Hit (To the Body)	138	0.81
1989	Slipping Away	103	1.69
1989	Terrifying	143	0.39
1989	Rock and a Hard Place	129	0.66
1989	Hearts for Sale	124	0.70
1989	Break the Spell	193	0.72
1989	Blinded by Love	112	1.04
1989	Can't Be Seen	142	0.81
1989	Almost Hear You Sigh	102	0.87
1989	Sad Sad Sad	152	0.43
1989	Mixed Emotions	137	0.53
1994	Love Is Strong	111	0.96
1994	Out of Tears	72	3.07
1994	Baby Break It Down	100	0.94
1994	Suck on the Jugular	106	0.76
1994	You Got Me Rocking	127	1.08
1997	Anybody Seen My Baby	105	0.01
1997	Flip the Switch	163	1.00
1997	Might as Well Get Juiced	85	0.20
1997	Saint of Me	122	0.29
1997	Gunface	99	1.47
1997	Out of Control	123	1.00
1997	Already Over Me	75	2.46
2002	Don't Stop	128	1.83
2005	Streets of Love	82	2.28
2005	Back of My Hand	85	1.29
2005	Rough Justice	138	0.90
2012	Doom and Gloom	132	0.54
2012	One More Shot	123	0.68
2016	Just Your Fool	116	0.76
Mean Year		**Mean Tempo**	**Tempo CV**
1977.9		119.6	1.62

Appendix Example 3 (end)

The 133 Rolling Stones studio recordings with Charlie Watts that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV).

Year	Title	Artist	Tempo	CV
1966	California Dreamin'	The Mamas & the Papas	112	0.96
1966	96 Tears	? and the Mysterians	124	0.93
1966	What Becomes of the Brokenhearted	Jimmy Ruffin	99	0.67
1966	Last Train to Clarksville	The Monkees	196	1.61
1966	Reach Out I'll Be There	Four Tops	120	0.99
1966	These Boots Are Made for Walkin'	Nancy Sinatra	166	1.31
1966	Cherish	The Association	110	1.58
1966	Strangers in the Night	Frank Sinatra	90	8.98
1966	Kicks	Paul Revere & the Raiders	131	1.51
1966	Ballad of the Green Berets	SSgt Barry Sadler	84	0.90
1968	Hey Jude	The Beatles	74	1.47
1968	Love Is Blue	Paul Mauriat	106	0.67
1968	Honey	Bobby Goldsboro	93	0.95
1968	(Sittin' On) The Dock of the Bay	Otis Redding	104	0.63
1968	People Got to Be Free	The Rascals	127	1.42
1968	Sunshine of Your Love	Cream	115	0.93
1968	This Guy's in Love	Herb Alpert	84	1.90
1968	The Good, the Bad and the Ugly	Hugo Montenegro	116	1.17
1968	Mrs. Robinson	Simon & Garfunkel	183	0.90
1968	Tighten Up	Archie Bell & the Drells	127	2.67
1970	Bridge over Troubled Water	Simon & Garfunkel	83	1.57
1970	(They Long to Be) Close to You	The Carpenters	89	1.23
1970	American Woman	The Guess Who	93	1.10
1970	Raindrops Keep Fallin' on My Head	B.J. Thomas	106	1.87
1970	War	Edwin Starr	109	1.74
1970	Ain't No Mountain High Enough	Diana Ross	97	2.28
1970	I'll Be There	The Jackson 5	95	2.30
1970	Get Ready	Rare Earth	137	1.48
1970	Let It Be	The Beatles	71	3.39
1970	Band of Gold	Freda Payne	110	0.84
1972	The First Time Ever I Saw Your Face	Roberta Flack	62	2.84
1972	Alone Again (Naturally)	Gilbert O'Sullivan	86	0.90
1972	American Pie	Don McLean	139	1.42
1972	Without You	Harry Nilsson	65	1.94
1972	The Candy Man	Sammy Davis Jr.	131	0.91
1972	I Gotcha	Joe Tex	94	0.93
1972	Lean on Me	Bill Withers	74	2.03
1972	Baby, Don't Get Hooked on Me	Mac Davis	82	1.51
1972	Brand New Key	Melanie	84	1.63
1972	Daddy Don't You Walk So Fast	Wayne Newton	74	0.93
1974	The Way We Were	Barbra Streisand	67	3.33
1974	Seasons in the Sun	Terry Jacks	99	1.46
1974	Love's Theme	Love Unlimited Orchestra	97	0.92
1974	Come and Get Your Love	Redbone	107	1.54
1974	Dancing Machine	The Jackson 5	109	0.97
1974	The Loco-Motion	Grand Funk Railroad	125	0.78
1974	TSOP (The Sound of Philadelphia)	MFSB	114	0.89
1974	The Streak	Ray Stevens	120	1.01
1974	Benny and the Jets	Elton John	66	0.96
1974	One Hell of a Woman	Mac Davis	121	1.13

Appendix Example 4

The 150 songs from year-end Billboard Top 10 rankings that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV).

Year	Title	Artist	Tempo	CV
1976	Silly Love Songs	Wings	125	1.08
1976	Don't Go Breaking My Heart	Elton John & Kiki Dee	132	0.79
1976	Disco Lady	Johnnie Taylor	104	1.42
1976	December, 1963 (Oh What a Night)	The Four Seasons	104	0.92
1976	Play That Funky Music	Wild Cherry	109	0.79
1976	Kiss and Say Goodbye	The Manhattans	65	1.14
1976	Love Machine	The Miracles	144	0.68
1976	50 Ways to Leave Your Lover	Paul Simon	102	0.86
1976	Love Is Alive	Gary Wright	98	0.21
1976	A Fifth of Beethoven	Walter Murphy & The Big Apple Band	109	1.37
1978	Shadow Dancing	Andy Gibb	102	0.90
1978	Night Fever	Bee Gees	109	0.27
1978	You Light Up My Life	Debby Boone	77	2.40
1978	Stayin' Alive	Bee Gees	104	0.10
1978	Kiss You All Over	Exile	102	1.02
1978	How Deep Is Your Love	Bee Gees	105	0.51
1978	Baby Come Back	Player	96	0.88
1978	(Love Is) Thicker Than Water	Andy Gibb	78	1.73
1978	Boogie Oogie Oogie	A Taste of Honey	125	1.41
1978	Three Times a Lady	Commodores	75	1.66
1979	My Sharona	The Knack	148	1.03
1979	Bad Girls	Donna Summer	120	0.28
1979	Le Freak	Chic	118	0.46
1979	Da' Ya' Think I'm Sexy?	Rod Stewart	112	0.76
1979	Reunited	Peaches & Herb	75	0.33
1979	I Will Survive	Gloria Gaynor	117	0.16
1979	Hot Stuff	Donna Summer	125	0.27
1979	Y.M.C.A.	Village People	127	0.84
1979	Ring My Bell	Anita Ward	125	0.25
1979	Sad Eyes	Robert John	71	0.24
1980	Call Me	Blondie	104	0.35
1980	Another Brick in the Wall (Part II)	Pink Floyd	104	0.65
1980	Magic	Olivia Newton-John	104	0.15
1980	Rock With You	Michael Jackson	114	0.24
1980	Do That to Me One More Time	Captain & Tennille	90	0.36
1980	Crazy Little Thing Called Love	Queen	155	1.29
1980	Coming Up	Paul McCartney	129	0.96
1980	Funkytown	Lipps Inc.	122	0.19
1980	It's Still Rock and Roll to Me	Billy Joel	141	1.73
1980	The Rose	Bette Midler	64	3.59
1982	Physical	Olivia Newton-John	124	0.09
1982	Eye of the Tiger	Survivor	109	0.44
1982	I Love Rock 'n Roll	Joan Jett & The Blackhearts	95	1.81
1982	Ebony and Ivory	Paul McCartney and Stevie Wonder	81	0.20
1982	Centerfold	The J. Geils Band	114	0.45
1982	Don't You Want Me Baby	The Human League	118	0.02
1982	Jack & Diane	John Cougar	103	0.25
1982	Hurts So Good	John Cougar	125	0.49
1982	Abracadabra	Steve Miller Band	128	0.51
1982	Hard to Say I'm Sorry	Chicago	72	1.35
1984	When Doves Cry	Prince	126	0.09

Appendix Example 4 (continued)

The 150 songs from year-end Billboard Top 10 rankings that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV).

Year	Title	Artist	Tempo	CV
1984	What's Love Got to Do With It	Tina Turner	98	0.07
1984	Say Say Say	Paul McCartney and Michael Jackson	117	0.31
1984	Footloose	Kenny Loggins	174	0.34
1984	Against All Odds (Take a Look at Me Now)	Phil Collins	58	0.14
1984	Jump	Van Halen	131	1.28
1984	Hello	Lionel Richie	62	0.99
1984	Owner Of a Lonely Heart	Yes	125	0.25
1984	Ghostbusters	Ray Parker Jr.	115	0.08
1984	Karma Chameleon	Culture Club	184	0.63
1986	That's What Friends Are For	Dionne and Friends	60	0.23
1986	Say You, Say Me	Lionel Richie	64	0.23
1986	I Miss You	Klymaxx	70	0.18
1986	On My Own	Patti LaBelle and Michael McDonald	92	0.03
1986	Broke Wings	Mr. Mister	99	0.03
1986	How Will I Know	Whitney Houston	120	0.04
1986	Party All the Time	Eddie Murphy	135	0.04
1986	Burning Heart	Survivor	98	0.40
1986	Kyrie	Mr. Mister	90	0.14
1986	Addicted to Love	Robert Palmer	112	0.62
1990	Hold On	Wilson Phillips	98	0.01
1990	It Must Have Been Love	Roxette	81	0.01
1990	Nothing Compares 2 U	Sinéad O'Connor	60	0.28
1990	Poison	Bell Biv DeVoe	112	0.15
1990	Vogue	Madonna	116	0.20
1990	Vision of Love	Mariah Carey	69	4.11
1990	Another Day in Paradise	Phil Collins	102	0.07
1990	Hold On	En Vogue	97	0.01
1990	Cradle of Love	Billy Idol	144	0.01
1990	Blaze of Glory	Jon Bon Jovi	79	1.20
1995	Gangsta's Paradise	Coolio featuring L.V.	80	0.01
1995	Waterfalls	TLC	86	0.01
1995	Creep	TLC	93	0.01
1995	Kiss From a Rose	Seal	132	0.40
1995	On Bended Knee	Boyz II Men	58	0.08
1995	Another Night	Real McCoy	126	0.02
1995	Fantasy	Mariah Carey	102	0.15
1995	Take a Bow	Madonna	80	0.05
1995	Don't Take It Personal (Just One of Dem Days)	Monica	89	0.12
1995	This Is How We Do It	Montell Jordan	104	0.02
2021	Levitating	Dua Lipa	103	0.41
2021	Save Your Tears	The Weeknd and Ariana Grande	118	0.01
2021	Blinding Lights	The Weeknd	171	0.01
2021	Mood	24kGoldn featuring Iann Dior	91	0.01
2021	Good 4 U	Olivia Rodrigo	167	0.88
2021	Kiss Me More	Doja Cat featuring SZA	111	0.01
2021	Leave the Door Open	Silk Sonic (Bruno Mars and Anderson .Paak)	74	0.10
2021	Drivers License	Olivia Rodrigo	144	0.63
2021	Montero (Call Me by Your Name)	Lil Nas X	90	0.31
2021	Peaches	Justin Bieber featuring Daniel Caesar and Giveon	90	0.26
Mean Year			**Mean Tempo**	**Mean CV**
1981.4			105.8	0.89

Appendix Example 4 (end)

The 150 songs from year-end Billboard Top 10 rankings that were analyzed for tempo variability, shown with their tempo coefficient of variation (CV).

Year	Title	Artist	Tempo	CV
1935	Can the Circle Be Unbroken	The Carter Family	98	2.74
1949	All She Wants to Do Is Rock	Wynonie Harris	149	1.94
1954	Blue Moon of Kentucky	Elvis Presley	112	1.01
1954	I Just Want to Make Love to You	Muddy Waters	81	3.64
1954	Shake, Rattle and Roll	Bill Haley & His Comets	167	0.84
1954	I've Got a Woman	Ray Charles and His Band	198	1.88
1956	Ride Em on Down	Eddie Taylor	187	1.08
1956	Smokestack Lightning	Howlin' Wolf	145	0.95
1956	Roll over Beethoven	Chuck Berry	186	1.29
1957	School Days	Chuck Berry	131	0.62
1962	Just Your Fool	Little Walter	109	0.80
1963	Pain in My Heart	Otis Redding	164	1.50
1963	Shame, Shame, Shame	Jimmy Reed	161	1.01
1964	I Get Around	The Beach Boys	148	2.54
1964	You Never Can Tell	Chuck Berry	131	0.68
1965	Michelle	The Beatles	116	2.74
1965	We Can Work It Out	The Beatles	107	2.93
1965	Mr. Tambourine Man	The Byrds	120	2.04
1965	My Generation	The Who	191	2.53
1966	Commit a Crime	Howlin' Wolf	124	0.90
1966	Rain	The Beatles	108	2.71
1966	Eight Miles High	The Byrds	130	1.66
1966	Lady Jane	The Rolling Stones (no drums)	102	1.54
1967	Purple Haze	The Jimi Hendrix Experience	108	2.39
1967	Daydream Believer	The Monkees	126	1.15
1967	Hey Joe	The Jimi Hendrix Experience	84	2.06
1967	White Rabbit	Jefferson Airplane	105	1.44
1967	Strange Brew	Cream	107	0.80

Year	Title	Artist	Tempo	CV
1967	Heroin	The Velvet Underground	125	18.00
1968	Blackbird	The Beatles	94	1.40
1968	All Along the Watchtower	The Jimi Hendrix Experience	115	2.34
1968	Voodoo Chile (Slight Return)	The Jimi Hendrix Experience	89	2.21
1968	Revolution	The Beatles	121	1.73
1968	I'm So Tired	The Beatles	71	3.76
1969	Come Together	The Beatles	83	1.61
1969	Cinnamon Girl	Neil Young & Crazy Horse	104	1.23
1969	Saved by the Bell	Robin Gibb	65	0.56
1969	Cissy Strut	The Meters	89	1.75
1969	You Can't Always Get What You Want*	The Rolling Stones (Miller on drums)	89	5.87
1970	Since I've Been Loving You	Led Zeppelin	119	2.96
1970	Somebody's Watching You	Little Sister	112	0.14
1970	Stanga	Little Sister	91	0.16
1970	Helpless	Crosby, Stills, Nash & Young	58	1.25
1970	Thank You (Falettinme Be Mice Elf Agin)	Sly and the Family Stone	106	0.78
1971	Family Affair	Sly and the Family Stone	109	0.27
1971	What's Going On	Marvin Gaye	101	1.19
1971	How Can You Mend a Broken Heart	The Bee Gees	69	3.03
1971	Imagine	John Lennon	76	1.06
1971	Never Can Say Goodbye	The Jackson 5	83	1.04
1972	Love Train	The O'Jays	123	0.81
1972	Do It Again	Steely Dan	125	0.77
1972	Let's Stay Together	Al Green	102	1.31
1972	How I Got Over	Aretha Franklin	157	1.51
1972	Hang on to Yourself	David Bowie	180	2.46

Appendix Example 5

154 additional songs by other artists analyzed for tempo variability (CV).

Year	Title	Artist	Tempo	CV
1972	Get on the Good Foot (Parts 1 & 2)	James Brown	108	1.03
1972	Shine a Light	The Rolling Stones (Miller on drums)	79	6.79
1973	Get Up, Stand Up	The Wailers	156	0.80
1973	If You Want Me to Stay	Sly and the Family Stone	102	0.22
1973	The Love I Lost	Harold Melvin & The Blue Notes	124	0.74
1973	Could It Be I'm Falling in Love	The Spinners	103	1.76
1973	Let's Get It On	Marvin Gaye	84	1.17
1973	Higher Ground	Stevie Wonder	125	1.14
1973	Time	Pink Floyd	64	4.51
1974	Rock Your Baby	George McCrae	104	0.23
1974	Shirley	Ron Wood	89	0.39
1974	Crotch Music	Ron Wood	131	0.26
1974	No Woman, No Cry	Bob Marley and the Wailers	99	0.19
1974	Toro Mata	Celia & Johnny	114	3.94
1974	Never Can Say Goodbye	The Jackson 5	126	0.65
1974	Waterloo	ABBA	147	0.94
1974	It's Only Rock 'n Roll (But I Like It)	The Rolling Stones (Jones on drums)	129	1.00
1975	Born to Run	Bruce Springsteen	147	2.32
1975	Fly, Robin, Fly	Silver Convention	100	0.21
1975	Love to Love You Baby	Donna Summer	96	0.28
1975	Fame	David Bowie	95	0.90
1975	Give Up the Funk (Tear the Roof off the Sucker)	Parliament	106	1.31
1975	That's the Way (I Like it)	KC and the Sunshine Band	109	1.08
1976	53rd and 3rd	Ramones	135	1.67
1976	Beat on the Brat	Ramones	158	1.30
1976	Live Wire	AC/DC	133	1.45
1976	Disco Inferno	The Trammps	129	0.91
1976	Dancing Queen	ABBA	101	0.40
1976	Daddy Cool	Boney M.	124	0.34
1976	You Should Be Dancing	The Bee Gees	124	0.61
1977	Dreams	Fleetwood Mac	120	0.69
1977	Hell Ain't a Bad Place to Be	AC/DC	128	1.23
1977	Seventeen	Sex Pistols	144	1.27
1977	Trans Europa Express	Kraftwerk	108	0.12
1978	One Way or Another	Blondie	162	1.42
1978	So Lonely	The Police	158	2.57
1978	Take Me to the River	Talking Heads	100	1.89
1979	Highway to Hell	AC/DC	116	1.17
1979	Powderfinger	Neil Young & Crazy Horse	107	1.07
1979	I Was Made for Loving You	KISS	129	0.24
1980	Back in Black	AC/DC	94	2.21
1980	You Shook Me All Night Long	AC/DC	127	1.99
1980	Another One Bites the Dust	Queen	110	0.19
1980	De Do Do Do, De Da Da Da	The Police	147	0.70
1980	9 to 5	Dolly Parton	104	2.39
1980	Hells Bells	AC/DC	106	3.70
1981	Dancing with Myself (Remix)	Billy Idol	177	0.50
1981	Give It to Me Baby	Rick James	123	0.58
1982	Billie Jean	Michael Jackson	117	0.26
1982	Another One Bites the Dust (Live Milton Keynes)	Queen	117	1.35
1983	Rebel Yell	Billy Idol	167	0.35

Appendix Example 5 (continued)

154 additional songs by other artists analyzed for tempo variability (CV).

Year	Title	Artist	Tempo	CV
1983	Every Breath You Take	The Police	117	0.22
1984	Born in the U.S.A.	Bruce Springsteen	122	2.15
1984	For Whom the Bell Tolls	Metallica	118	0.58
1985	Just Another Night	Mick Jagger	132	0.47
1986	Who Made Who	AC/DC	126	1.24
1986	Sleep Tonight	The Rolling Stones (Wood on drums)	74	2.25
1987	Sweet Child O' Mine	Guns N' Roses	126	1.31
1987	Just Like Heaven	The Cure	151	0.96
1988	Make No Mistake	Keith Richards	92	0.66
1988	Meanstreak	AC/DC	98	0.65
1989	Romeo Had Juliet	Lou Reed	131	1.09
1989	About a Girl	Nirvana	133	1.47
1990	Thunderstruck	AC/DC	134	0.94
1991	Smells Like Teen Spirit	Nirvana	117	1.28
1991	Enter Sandman	Metallica	124	0.96
1991	Lithium (Live Paradiso)	Nirvana	129	2.13
1991	Lithium (Alternative Take)	Nirvana	124	2.85
1991	Lithium (Montage of Heck)	Nirvana	123	0.23
1991	Lithium	Nirvana	123	0.20
1991	Something in the Way	Nirvana	52	2.37
1992	999	Keith Richards	127	1.24
1993	Evening Gown	Mick Jagger	78	1.38
1993	Sweet Thing	Mick Jagger	105	0.33
1993	Stick It Out	Rush	120	0.28
1993	Babies	Pulp	158	2.76
1994	Feel the Pain	Dinosaur Jr.	149	10.40
1996	If It Makes You Happy	Sheryl Crow	95	0.30
1997	My Heart Will Go On	Celine Dion	50	0.34
2000	The Root	D'Angelo	80	0.25
2000	The Line	D'Angelo	80	0.28
2001	Last Nite	The Strokes	208	0.45
2003	Seven Nation Army	The White Stripes	123	2.00
2005	Train Under Water	Bright Eyes	126	3.87
2006	Workinonit	J Dilla	93	0.72
2009	Need You Now	Lady Antebellum	108	0.23
2011	Yellow (Live Madrid)	Coldplay	96	1.42
2011	Every Teardrop is a Waterfall	Coldplay	118	0.16
2015	Sugar	Maroon 5	120	0.16
2015	Love Yourself	Justin Bieber	100	0.37
2017	Paradise (Live Rose Bowl)	Coldplay	70	0.24
2018	Fix You (Live Sao Paulo)	Coldplay	70	0.37
2019	Yellow (Live Toronto)	Coldplay	85	1.14
2020	Break My Heart	Dua Lipa	113	0.54
2022	All Down the Line	Blackberry Smoke	140	1.11
2023	What Was I Made For?	Billie Eilish	78	0.77
2023	bad idea right?	Olivia Rodrigo	130	0.01
2023	Did You Know That There's a Tunnel Under Ocean Blvd.	Lana Del Rey	60	0.32
2023	Angry	The Rolling Stones (Jordan on drums)	113	0.63
2023	Sweet Sounds of Heaven (Single Edit)	The Rolling Stones (Jordan on drums)	43	0.96
Mean Year			***SD***	**Mean CV**
1980.0			1.88	1.48

Appendix Example 5 (end)

154 additional songs by other artists analyzed for tempo variability (CV).