Spectrogram-Based Analysis of Expressive Gestures:
Classification Approaches for Articulation, Pitch Vibrato, and Portamento

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Expressive Sound Gestures have been a subject of debate since the beginnings of literature on musical performances.[1] Since they are immediate expressions of subjective interpretation processes, Expressive Sound Gestures (henceforth: Expressive Gestures) are not necessarily prescribed in scores following the Western tradition of musical notation. Therefore, they can be assessed in their full dimension only through a close analysis of the performances themselves. The development of sound recording provided us with new sources to capture some of those elements from the late 19th century onwards, and with the introduction of waveform visualisations and spectrograms (or spectral waterfalls, sonograms, voiceprints, voicegrams, respectively) in the second half of the 20th century, it even became possible to create visual representations of musical performances, allowing for a powerful evaluation method that complements close and distant listening approaches. Since at least the introduction of the SONIC VISUALISER (SV) in 2007, sound visualisation has become an integral and easily accessible way of software-based analysis for musicological purposes.

However, comprehensive classifications for what is seen in visualisations of Expressive Gestures are pending. Moreover, musicological and pedagogical literature has discussed aspects of the production, the aesthetic qualities, or the (historical) reception of expressive means such as articulation, vibrato, and portamento, but it often missed efficient descriptions for the actually *sounding* phenomena.[2] This, in large part, may be due to a lack

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1 The term "Expressive Sound Gesture" should be understood as an auxiliary one here, since although the concept of "gesture" in musical contexts has been controversially debated, a persuasive definition still seems to be pending. For the purpose of this study, it shall denominate a *meaningful combination of shortest sounding elements in performance practice that essentially emanate from the subjectivity of a performing individual*. Such may involve (aspects of) micro-timing, articulation, vibrato, portamento, or changes in timbre, on single notes or to interconnect multiple notes, but they theoretically are limitless and strongly depend on musical genres and regional performance traditions.

2 For instance, most vocal and instrumental schools focus on *how* to produce articulation, vibrato, and portamento, but they omit descriptions of rates, ranges, dynamics, durations, or noise components (to name but a few). Moreover, frequent attributes such as "sharp" or "soft" (articulation), "fast" or "wide" (vibrato), "broad" or "plain" (portamento) usually lack absolute references – *how* fast is

of propositions on how to actually 'measure' these phenomena (except perhaps for vibrato)[3]. However, classifications based on viable quantification frameworks should still be compatible with established concepts from historical sources[4] and existing approaches from neighbouring research areas[5] in order to create purposeful findings on various performance strategies.

Ultimately, recordings never have been representations of musical performances alone; they also represent the respective technologies in place. In other words, when analysing performances on record, we are working with sources that are profoundly manipulated due to the limitations of (historical) recording and reproduction devices, the storage media, or the digital transfer technologies. Spectrogram-based classifications may help with differentiations between actual performance elements and technical artefacts which otherwise might be difficult to retrace.[6]

My following contribution shall therefore make proposals on how to measure and evaluate some Expressive Gesture phenomena by means of spectrograms. Comprehensive classifications for articulation, pitch vibrato and portamento will be introduced (section 1 and 2) and it will be discussed when to consider them as Expressive Gestures (section 3). Due to my own research, the classifications will focus on violin sounds and violin performance practice, but they may allow for cross-referencing or even application to other (Western) string instruments, wind instruments, and singing. Subsequently, an implementation of the classifications will be exemplified by a brief analysis of three historical performances of Ludwig van Beethoven's Violin Concerto in D Major, Op. 61 – to be precise, only two bars of the second movement – in recordings by Bronisław Huberman (1934), Erich Röhn (1944), and Henryk Szeryng (1953).

However, even the explanatory power of spectrograms is far from "objective" but strongly dependent on the subjective assessment of the researcher. Therefore, it may be helpful to take a close look at the principles of spectrograms and their underlying feature, the Fast Fourier Transformation,

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"fast"? Is a "wide" vibrato, executed by a big hand, as wide as a vibrato executed by a small hand? How much impulse and / or noise is needed for a "sharp" accent?

3 See Tilo Hähnel's contribution to this volume: "Automatisierte Vibratoanalyse", pp. 269–288, here pp. 270–273.

4 In violin performance this might refer to bowing types (German: "Stricharten", such as *detaché* or *spiccato*) or vibrato production strategies (as implied by terms like "finger", "hand", or "arm vibrato"; also see note 2).

5 For instance, findings from (musical) acoustics, psychoacoustics, or phonetics on sound production, sound components and sound reception.

6 Such as musical accents, 'real' dynamics and vibratos, and original timbre qualities as opposed to technical noises and cracks, boosts at certain frequency regions, wow and flutter, or timbre losses due to digital conversion processes.

prior to the reading of this text.[7] Finally, this volume's repository provides a number of supporting sound examples, all given figures in high resolution, and an Excel template that allows for quick computation of the Inflection Indices provided for each articulation, vibrato, and portamento type. At the current state, all measurements and evaluations related to these classifications still have to be done 'manually', though the development of automated Vamp Plugins for SV is intended.[8]

1. Classifications

Articulation, vibrato, and portamento are highly time-sensitive and frequency-sensitive means of expression. Therefore, analysing them with the help of spectrograms rather than waveform visualisations (which lack frequency domains) or by omitting visualisations at all (which would entirely subordinate the quality of the analysis to the researcher's subjective listening capacities) seems to be reasonable. Moreover, spectrograms enable us to virtually quantify some expressive aspects such as rates, ranges, and (amplitude) levels by using the data output of the Fourier analysis. Therefore, the following classifications are illustrated by spectrograms of exemplary gesture incidents, captured from historical recordings between 1934 and 1953 (see FIGURES 1.1–3.2).[9] However, it is strongly recommended to perform analyses both by visual *and* auditory evaluations – particularly because two senses might work better together to distinguish between actual musical events and technical artefacts due to the recording or transfer processes.[10] Thus, the same recordings are made accessible in the online repository accompanying this volume (see APPENDIX 2).

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7 See, e.g., "Preparing Spectrograms in SONIC VISUALISER: Measuring Time-Sensitive and Frequency-Sensitive Performance Aspects" in this volume (pp. 95–113).

8 For updates, please check the *Vamp Plugins* homepage of the Centre for Digital Music, Queen Mary Institute (University of London), https://www.vamp-plugins.org/download.html, 24.02.2022, or the Zenodo online repository associated with this volume: *Musical Performance Research: Data and Software*, https://zenodo.org/communities/musperf_data, 24.02.2022.

9 As Hermann Gottschewski rightly objected during the conference, spectrograms generated based on the *Fast Fourier Transformation* (FFT) may not be perfectly suited to perform precise measurements on bowed string instrument sounds – because of their sawtooth waveforms, which may be slightly 'cut off' by Fourier transforms (or, more accurate: falsely interpreted as sine waves) and, therefore, might affect both pitch and level representation in frequency domain. Unfortunately, SV does not provide alternative spectrogram algorithms and, to my knowledge, proven alternatives do not exist so far. Gottschewski suggested to program an application which decomposes sawtooth waveforms by reading out the original complex wave signal for the distances between its characteristic spikes.

10 Also see on this topic Thomas Wozonig's text on tempo measurements in this volume (pp. 73–98, esp. pp. 85–94).

1.1 Articulation

Deviating from common definitions, *articulation* for the purpose of this approach is understood as the entity of (1) noise components at the beginning (attack and initial decay phase), (2) subsequent dynamic developments in terms of level (sustain phase), and (3) the overall duration (attack–release phases) of a single sound in relation to its enveloping Inter-Onset Interval.[11] This definition restricts articulation to single notes in relation to their subsequent notes, indicating elements such as accents or various bowing techniques. Furthermore, it excludes expressive means like vibrato, portamento, or (changes in) timbre, which are often commonly added to articulation as well, but may instead each require separate treatment and measurement methods. FIGURE 1.1 (figures starting at p. 208, also see the attendant sound examples) represents the structure of articulation as a concept understood that way. According to the above definition, it consists of three components: (1) impulse, (2) volume development, and (3) duration. To identify these subclasses in SV's spectrogram view, you may choose an FFT window size of 2,048 (given a sampling rate of 44.1 kHz) with maximum overlap properties (93.75%) and a colour scale set to "Meter" or "dV ^ 2", so background and surface noises that are not being part of the actual performance will be largely elided in the visualisation.[12]

(1) Impulse

The concept of understanding articulation in violin performance as a function of its noise level is supported by findings from the field of musical acoustics. As Donald Hall puts it, violin sounds are exemplary for the "stick-slip mechanism" of the bow stimulating the string: the bow sticks to the string, pulling it aside until it slips away. This moment of 'slipping' entails a noise effect, which in its extent depends on the energy expended for the bow impulse.[13] The noise level may be particularly high at the very beginning (attack) of a violin sound and – together with volume and duration

11 This definition is derived from the ADSR units of a single tone (Attack, Decay, Sustain, Release), that is, their changing amplitude profile; cf. Donald E. Hall, *Musical Acoustics*, Pacific Grove [3]2002, pp. 140f. For the purpose of this approach, "tone" means a pitch fundamental and its overtones, whereas "sound" is understood as the entity of audible qualities related to the realisation of a single note (that is, both periodic and non-periodic components such as tone *and* noise). Since strongly noise-related, the following classification for articulation will use the term "sound", whereas the subsequent classifications for vibrato and portamento will speak of "tone".

12 Cf. Vollmer, "Preparing Spectrograms" (note 7), pp. 4ff.

13 See Hall, *Musical Acoustics* (note 11), pp. 207–212. Interestingly, the rapid waveform alterations that are largely due to the noise ratio at the beginning (attack) and ending (release, together called "transients") of a sound also seem to decide to a

of the sound – determines the distinctness of single notes in comparison with neighbouring notes.

Historically, this noise-tone ratio often led to comparisons with spoken language, as is apparent from numerous violin schools of the 19th and 20th centuries (of which the following are a small selection only): In the third volume of his influential method (*Du style*, 1858), Charles de Bériot persistently illustrated articulation on the violin by using terms like "prononciation", "ponctuation", or "syllabation".[14] Karl Klingler (1921) directly compared the onset of the *martelé* ('hammered') bowing technique with the (German) consonants d, t, g, and k;[15] and for Carl Flesch (1929), *martelé* and *staccato* bowing techniques were based on "side noises" due to "pressure accents" at the tone onset.[16] Likewise, in his 1962 textbook, Ivan Galamian drew parallels between "bow attack" and phonetics in distinguishing between (1) "the very smooth, vowel-like beginning", (2) "the clearly defined consonant-like attack", and (3) "the accented attack".[17]

In fact, these comparisons seem to be productive: in German phonetics, the manners of articulation[18] of the shortest distinguishable units in spoken language (phones) are typically classified into sonorants and obstruents. Sonorants, such as *vowels* or *vibrants* (trills), are characterised by letting air pass in the vocal tract largely unobstructed; therefore, they cause relatively little noise. Obstruents, by contrast, generate plenty of noise by short-term obstruction of the air stream, as in most consonants. They may be further divided into three subclasses based on their modes of obstruction, all three of which are of particular interest when compared to violin sound onsets: plosives, fricatives, and affricatives. *Plosives* are closure sounds resulting from short-term blockades of the air stream (such as pressing the lips together), leading to a build-up of air pressure and an 'explosive' sound at the moment of release. *Fricatives* denote friction sounds evolving from air turbulence due to constrictions in the vocal tract (like

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large extent on the human capacity of distinguishing different instruments; cf. ibid., p. 108.

14 Charles-Auguste de Bériot, *Méthode de Violon* Op. 102, vol. 3: *Du style*, Paris / Mainz: Schott n. d. [1857/58, plate no. C. B. 21.], esp. p. 176.

15 Karl Klingler, *"Über die Grundlagen des Violinspiels"* [first publ. 1921] *und nachgelassene Schriften*, ed. by Marianne M. Klingler and Agnes Ritter, Hildesheim etc. 1990, p. 65.

16 Carl Flesch, *Die Kunst des Violinspiels. I. Band: Allgemeine und angewandte Technik* [1923], Berlin ²1929, p. 49: "Nebengeräusche" and "Druckakzente" (my translations).

17 Ivan Galamian, *Principles of Violin Playing & Teaching*, Englewood Cliffs ²1985, pp. 84f. (same wording as in the first edition 1962).

18 *Manners of articulation* (German: "Artikulationsmodi oder -arten") in phonetics refer to specific modes of pronunciation that do not directly link to *places* of articulation ("Artikulationsorte") within the vocal tract, which is why a comparison to bowed string sound seems viable within certain limits.

moving the tongue close to the palate, or its tip to the teeth), resulting in a hissing noise. *Affricatives* are immediate successions of plosives and fricatives in one phone; that is, an 'explosive' sound seamlessly followed by a hissing noise.[19]

These classifications shall now be applied to violin onsets, for the manners of articulation in phonetics and those in violin performance are comparable to a certain extent: Sonorants allow for non-turbulent airflow within the vocal tract – for the violin, low-noise onsets are provided by low bow stiction and almost freely (that is: periodically) resonating strings. By contrast, obstruents restrain the airflow, and noisy onsets at the violin result from high bow stiction strongly impeding an overtly periodic string resonance. To point to these analogies, the phonetic terms shall be adopted to indicate different violin onsets (as already implied by Klingler and Galamian) and sorted in ascending order of noise ratio (see FIGURE 1.2 to compare with exemplary appearances in spectrograms, both for phones and the corresponding violin sounds):

- **sonorous** onsets (code "s"): minimal noise ratio – periodic oscillation (fundamentals and overtones) starts almost immediately, corresponds to onsets in *legato* or piano *detaché* stroke;
  spectral appearance: tones (fundamentals and overtones) only;
  phone equivalents: all vowels – [a], [e], [i], [o], [u], as in "start" [stɑːt], "end" [end] (British English); "Anfang" [anˌfaŋ], "Ende" [ɛndə] (German)

- **fricative** and **vibrant** (trill) onsets (code "f"): clearly perceptible friction noise at the beginning ('scratchy') – string resonance is obstructed by slightly higher bow stiction which continues beyond tone onset, corresp. to forte *detaché* or low *spiccato* strokes;
  spectral appearance: fog-like traces around tone onsets;
  phone equivalents: [f], [ʃ], [ð], [ç], [x], [ʁ], [ʀ], as in "fish" [fɪʃ], "shirt" [ʃɜːt] or "those" [ðəʊz] (no trills in British English); "ich" [ɪç], "lachen" [laxn̩], "rund" [ʁʊnt], "rot" [ʀoːt] (German);
  or combinations: [fx], [ʃʁ], [xʁ], [xʀ], [fxʀ], …

- **plosive** onsets (code "p"): full, but abrupt noise at the beginning (beat-like) – bow pulls string aside with high stiction and releases suddenly, also: percussive left-hand technique, both causing an 'explosive' onset, best corresponding to volume accents;
  spectral appearance: clearly visible noise 'columns' preceding the tone onset;
  phone equivalents: [p], [b], [d], [t], or [k], as in "ball" [bɔːl], "due" [djuː], "tone" [təʊn], and "cold" [kəʊld] (British English); "Ball" [bal], "dann" [dan], "Tag" [tag], "kalt" [kalt] (German)

19 See, e.g., T. Alan Hall, *Phonologie. Eine Einführung*, Berlin / New York 2000, pp. 5–29, for a brief overview on manners of articulation esp. pp. 21f.

- **'affricative'** onsets (code "a"):[20] combination of a plosive and a fricative / vibrant (trill) onset, strong noise components that sustain beyond tone onset – best corresponding to high forte *spiccato* or fortissimo *martelé;* *spectral appearance:* sharp columns through the whole spectrum, followed by fog-like traces around tone onset;
  phone equivalents: affricates like [tʃ], [dʒ], as in "choose" [tʃuːz], "joy" [d͡ʒɔɪ], "Kutsche" [kutʃə], "Dschungel" [d͡ʒʊŋl]; combinations like [kʀ] (transition of plosive to trill) as in "Kraft" [kʀaft] or [tʁ] (plosive to fricative) as in "Tracht" [tʁaxt]

(2) Volume development

Articulation of sound, both vocal and instrumental, also strongly depends on volume levels. This concerns level developments across multiple consecutive sounds as well as developments within *single* sounds, both at the moment of sound onset (attack / decay) and after (sustain / release).[21] Absolute onset levels and overarching level developments are omitted in this classification.[22] However, volume developments in the sustain stage of single sounds are taken into consideration, for they may not only indicate different bowing techniques but also create musical stress and structure.

Accordingly, volume developments are classified in relation to onset levels. To compensate for the proximity effect as well as potentially longer reverberation times of low frequencies due to the reflection characteristics in most recording studios,[23] volume developments should be measured at lower overtones (typically, the first or second; see spectrogram in FIGURE 1.1).

- **increasing** (code "<"): tone increases in volume level due to increasing bow stiction; corresponds to *crescendo;*
  spectral appearance: increasing dB values / colour depth

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[20] Note that the term "affricative" is used in an extended sense here to denominate analogies in violin sound to both actual affricatives and other immediate successions of plosives and fricatives / vibrants (trills) in order to indicate combined noise types. Therefore, the Inflection Index factor (cf. section 2.4) for "affricative" onsets simply adds the weights of "plosive" and "fricative" impulses.

[21] See Hall, *Musical Acoustics* (note 11), pp. 118f.

[22] This is due to two basic assumptions: First, absolute onset volumes largely depend on the energy expended for the sound impulse; thus, there already exists a correlation with the "impulse" subclass. Second, the relevance of absolute overall levels unfolds in comparison with multiple consecutive notes only, that is, in analysing whole musical passages. Hence, concerning single notes (as determined by the definition given above), a registration of *relative* developments within the sounds would be more effective here.

[23] See Hall, *Musical Acoustics* (note 11), p. 321 and pp. 358f.

- **increasing and decreasing** or inverse (code ":"): tone first increases, then decreases (or vice versa) in volume level; corresponds to swells (short-term *crescendo-decrescendo*) that are often applied in *tenuto* techniques;
  spectral appearance: increasing, then decreasing dB / colour depth

- **constant** (code "="): volume level remains almost unaltered; corresponds to bowing techniques such as *legato*, *grand detaché;*
  spectral appearance: (almost) no changes in dB / colour depth[24]

- **decreasing** (code ">"): tone decreases in volume level; corresponds to short-term *decrescendo* such as in most bouncing bow techniques (*spiccato*, *ricochet*);
  spectral appearance: decreasing dB values / colour depth

(3) Duration

Most definitions of the term "articulation" refer not only to the creation of single sounds but also to the conjunction of *two* sounds – that is, the ratio between sound duration and sound 'gap' between two consecutive onsets. Notably, Leopold Mozart, in the third edition (1787) of his famous violin school, already differentiated "Zusammenschleifen" (joining together) and "Alleinspielen" (playing separated) in notes of equal length, implying a basic distinction between tone successions with and without 'gaps'.[25] Roughly 150 years later, Carl Flesch specified not fewer than 18 distinct bowing techniques, classifying them in "four large families": "long", "short", "thrown", and "bouncing" techniques plus a "mixed" category[26] – tone duration, as is apparent, was the most decisive criterion here. Moreover, Flesch at one point suggested that "the crucial difference between long and short strokes" would not be "in their duration but in the presence or absence of a clearly noticeable rest between single notes".[27]

These differentiations of bowing techniques based on sound-rest ratios seem crucial for both acoustical and practical reasons: On the one hand, the shortening of certain notes plays a significant part in the communication of musical structure. As Hall puts it, the perception of "silent spaces

24 A tolerance of ±2 dB proved best corresponding to my personal perception.

25 Leopold Mozart, *Gründliche Violinschule* [1756], Augsburg [3]1787 (reprint Leipzig 1968), p. 123–136 ("Des siebenten Haupstücks erster Abschnitt. Von der Veränderung des Bogenstriches bey gleichen Noten").

26 Flesch, *Die Kunst des Violinspiels* (note 16), pp. 46–59, esp. p. 46: "Wir wenden uns […] den vier großen Familien der Stricharten zu: den langen, den kurzen, den geworfenen und springenden, schließlich den gemischten Strichen" (my translations).

27 Ibid., p. 48: "[B]ei näherem Zusehen wird man jedoch finden, daß […] der grundlegende Unterschied zwischen langen und kurzen Strichen nicht in deren Zeitdauer, sondern im Vorhanden- oder Nichtvorhandensein einer deutlich merkbaren Pause zwischen den einzelnen Noten liegt […]" (my translations).

as gaps" (together with the "change in the apparent loudness of the notes") forms the acoustical foundation of musical "[s]tress by articulation".[28] On the other hand, notes are seldomly played in full length according to the score; how they ultimately sound strongly depends on the performer's interpretation. In violin performance, this is apparent in bowing techniques such as naturally playing *spiccato* (bouncing strokes) in fast, vibrant passages as opposed to *legato* (slurred strokes) in slower, melancholic ones, no matter whether or not they are indicated by the score.

The implications of tone durations for the perception of musical articulation have been investigated in depth for piano performance, namely by Bruno Repp in the mid to late 1990s.[29] Repp (among others) used the term *Inter-Onset Interval* (IOI) to describe the duration between two subsequent tone onsets, adding that the degree of *legato* techniques in piano performance strongly depends on the *Key Overlap Time* (KOT) of consecutive tones. In the early 2000s, Roberto Bresin and Giovanni Umberto Battel applied the terms *Key Detached Time* (KDT, absolute values) and *Key Detached Ratio* (KDR, relative values) to further define the 'rest' between tone offsets and subsequent tone onsets (previously also referred to as Offset-Onset Interval, OOI), which can be used to describe *staccato* techniques.[30] It seems appropriate to take up these concepts and expand them, for Repp's, Bresin's and Battel's general findings on the nature and perception of *legato* and *staccato* sounds may correspond to articulation in violin (and other instruments, as well as vocal) performance. To do so, an additional term *Tone Duration* (TD) will be defined as time span from tone impulse (attack) to tone offset (end of release), where "offset" is assumed for a level of roughly -50 dBFS,[31] and given as a ratio to its enveloping IOI (or: IOI = TD + KDR). Thus, a TD of 0.5 IOI would indicate a tone duration of 50% of the time span between the respective tone's onset and the subsequent tone's onset.

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28 Hall, *Musical Acoustics* (note 11), p. 119.

29 See, e.g., Bruno Repp, "Acoustics, perception, and production of legato articulation on a digital piano", in: *Journal of the Acoustical Society of America* 97/6 (1995), pp. 3862–3874; idem, "Acoustics, perception, and production of legato articulation on a computer-controlled grand piano", in: *Journal of Acoustical Society of America* 102/3 (1997), pp. 1878–1890.

30 See Roberto Bresin / Giovanni Umberto Battel, "Articulation strategies in expressive piano performance. Analysis of legato, staccato, and repeated notes in performances of the Andante movement of Mozart's sonata in G major (K 545)", in: *Journal of New Music Research* 29/3 (2000), pp. 211–224, esp. p. 213, Fig. 2(b).

31 This value is determined based on a level decrease of 60 dB typically defining a full fade away of reverberation (see Hall, *Musical Acoustics* (note 11), p. 324), minus a small compensation of 10 dB for surface noises (particularly apparent in historical recordings), measured from the scale maximum (0 dBFS).

To evaluate TDs, higher overtones should be considered because of their typically shorter reverberation time.[32] To determine their duration, one may measure the time from onset to offset in spectrogram view (that is, until the respective overtone falls below c. -50 dBFS),[33] then relate the value to the time span from its onset to the next tone's onset. Alternatively, if a break follows, estimate a theoretical onset based on the score and the performer's tempo.[34] The TDs are then classified as follows:

- **secco** (code "S"): Tone Duration (TD) of <0.6 Inter-Onset Interval (IOI), corresponding to, e.g., *staccato*, high *spiccato*

- **elastico** (code "E"): TD of 0.6–0.95 IOI, corresponding to, e.g., *tenuto* or *sautillé*

- **lungo** (code "L"): TD of >0.95 IOI,[35] corresponding to, e.g., *slurred* or *grand detaché*

The boundary value given for *secco* durations is based on Bresin's and Battel's measurements of KDR values for *staccato* articulations in 45 piano performances, indicating a Q_1 (lower quartile) at c. 40%, which conversely

32 See note 23. However, some rooms may reverberate longer in higher frequency ranges; in these cases, choose the overtones with the shortest visible duration in the spectrogram. Since there always remains a reverberation proportion, an additional tolerance may be considered.

33 In SV spectrogram's default settings ("Green" map, threshold at -80 dBFS, no colour rotation), this is given for windows in dark green (below -60 dBFS) and light green (below -50 dBFS).

34 For instance, if a note, indicated by the score as a quarter, is played for the length of an eighth only (leaving a gap of another eighth's duration until the next tone's onset), this sound would represent 0.5 of the intended note duration and therefore be classified as "secco" (s). This, of course, becomes a bit more complicated in *rubato* passages or if a pause (*fermata*) follows. In these cases, estimates based on local acceleration or deceleration tendencies might help.

35 The terms *secco*, *elastico*, and *lungo* are understood here in a traditional sense as indications of duration relative to full note length (rather than indications of absolute note lengths). The benefit of this approach is in its greater robustness against tempo variance, since absolute values would lack any reference to IOIs and thus to tempo (that is, it would not be possible to maintain a distinction between "secco" and "lungo" lengths for varying tempos, especially if they become fast: consider absolute "lungo" lengths that exceed short IOIs). Moreover, as Bresin and Battel implied, relative indications may even better catch an empirical notion of articulation: In their set of *staccatos* measured within moderate IOIs (c. 200–480 ms), "[relative] KDR values [have been] almost constant, implying that staccato articulation is independent of [absolute] IOI", see Bresin / Battel, "Articulation strategies" (note 30), p. 219. However, even the indication of relative durations may be misleading in case of tempo extremes (e.g., consider a "secco" duration of 0.5 IOI in very slow tempos). Therefore, the actual (psychoacoustical) character of these durations should be determined case by case.

would equal a TD of 0.6 IOI.[36] For *lungo*, the boundary allows for some bow change time (since this subclass shall not only denote slurred notes) of an estimated 5%.

Ultimately, in melodies played on bowed string instruments, there typically is no such thing as *Key Overlap Time* (after Repp); exceptions include open string sounds, double stops, and arpeggios. This is due to the fingers of the left-hand that dampen preceding tones in the moment of a new onset. Therefore, all boundary values given here are below 1.

Type indicators

The codes given above for each subclass, consisting of one sign only, may now be combined to construct indicators of distinct articulation types (e.g., the code combination *a>S* refers to an affricative, decreasingly loud, short articulation, such as a *high spiccato*).[37] This coding system may allow for statistical evaluations of large-scale articulation measurements. Furthermore, FIGURE 1.1 indicates "subclass factor" values for each type (the small numbers given next to each type) as part of the Inflection Index I_{Art}, which will be explicated in section 2. The same applies to the following vibrato and portamento classifications.

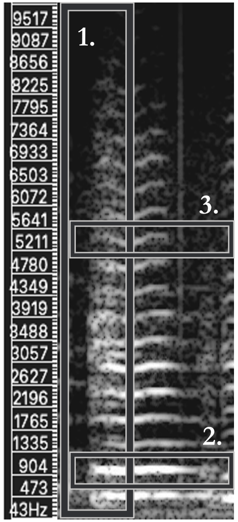
36 See ibid., Fig. 11. This means that 75% of the measured staccato values have been shorter than 0.6 IOI. On using quartiles as boundary values, see Julian Caskel's introductory text in this volume, pp. 119–144, esp. pp. 132–135.

37 It is important to note that a code combination does not *always* match a specific bowing technique or the other way around. For instance, a *spiccato* may sound longer or shorter depending on the bow's bouncing height; therefore, the term indicates an (technical) approach rather than the sounding result.

Articulation

systematic classification for bowed string instruments

incl. Articulation Index I_{Art}: *heuristic degree of articulation level* (ordinal scale from 8 to 100)



1. Impulse × **2. Volume Development** × **3. Duration**

1. Impulse (noise components at onset)		[a]	**2. Volume Development** (*after* impulse until offset, measured at overtones)		[b]	**3. Duration** (in relation to Inter-Onset Interval [IOI], measured at overtones)		[c]
a	'affricative' (beat-like *and* scratchy)	[5]	<	increasing	[1.25]	**S**	secco (short, <0.6 IOI)	[1.5]
p	plosive (beat-like)	[3]	:	in- and decreasing	[1.13]	**E**	elastico (separated, 0.6–0.95 IOI)	[1.25]
f	fricative / vibrant (scratchy)	[2]		de- and increasing		**L**	lungo (long, >0,95 IOI)	[1]
s	sonorous (almost noiseless)	[1]	=	constant (± 2 dB)	[1]			
			>	decreasing	[0.75]			

subclass factors [a×b×c] × scaling factor (10.7) =
Articulation Index $\mathbf{I_{Art}}$ (8–100)

Examples from traditional bowing terminology:

legato	–	*sonorous, constantly loud articulation, long*	**s=L**	(I_{Art} = 11)
sautillé	–	*fricative, decreasingly loud articulation, separated*	**f>E**	(I_{Art} = 20)
martelé	–	*plosive, constantly loud articulation, long*	**p=L**	(I_{Art} = 32)
spiccato (high)	–	*affricative, decreasingly loud articulation, short*	**a>S**	(I_{Art} = 60)

FIGURE 1.1: Articulation
Systematic classification for bowed string instruments

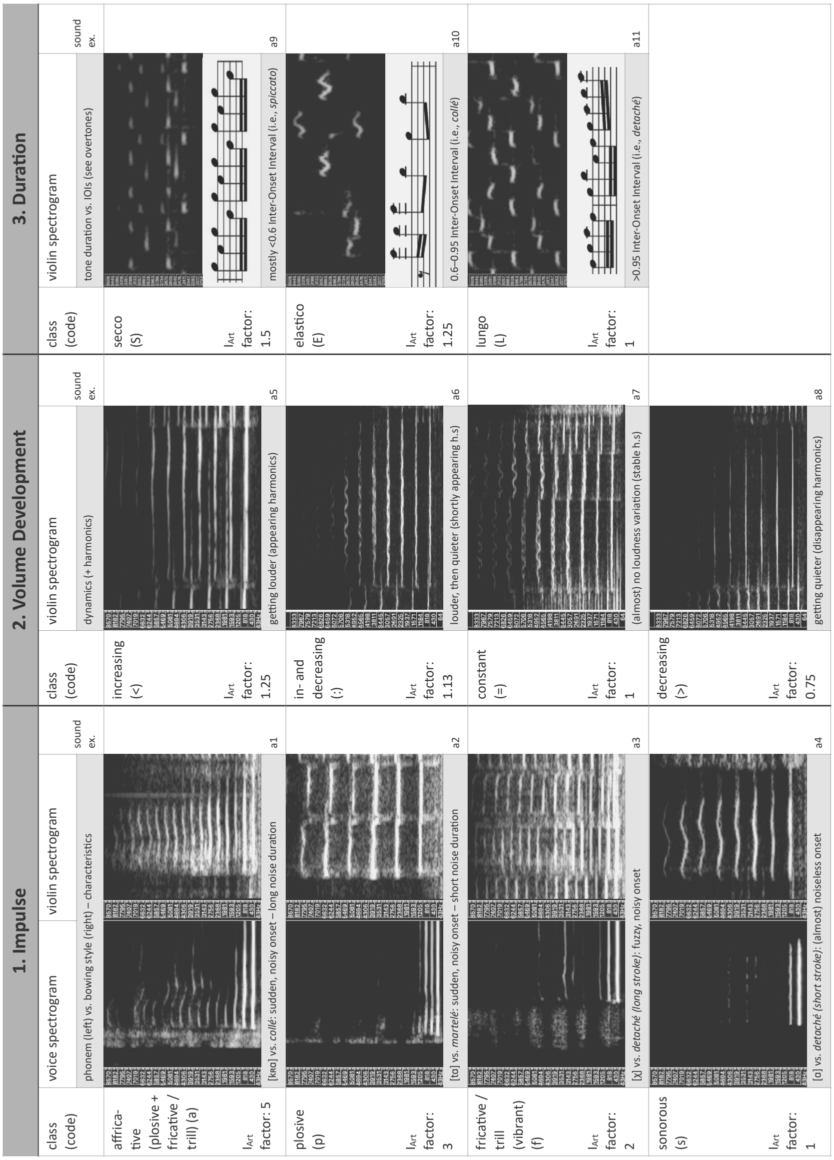


FIGURE 1.2: Examples of Articulation Subclasses
Determination based on spectrograms
x-axes: time in sec; y-axes: frequency in Hz
(*Impulse*, *Volume Dev.:* 0–9,000 Hz; *Duration:* 2,000–4,000 Hz; linear scales)[38]

[38] For figures in high definition, see accompanying online repository.

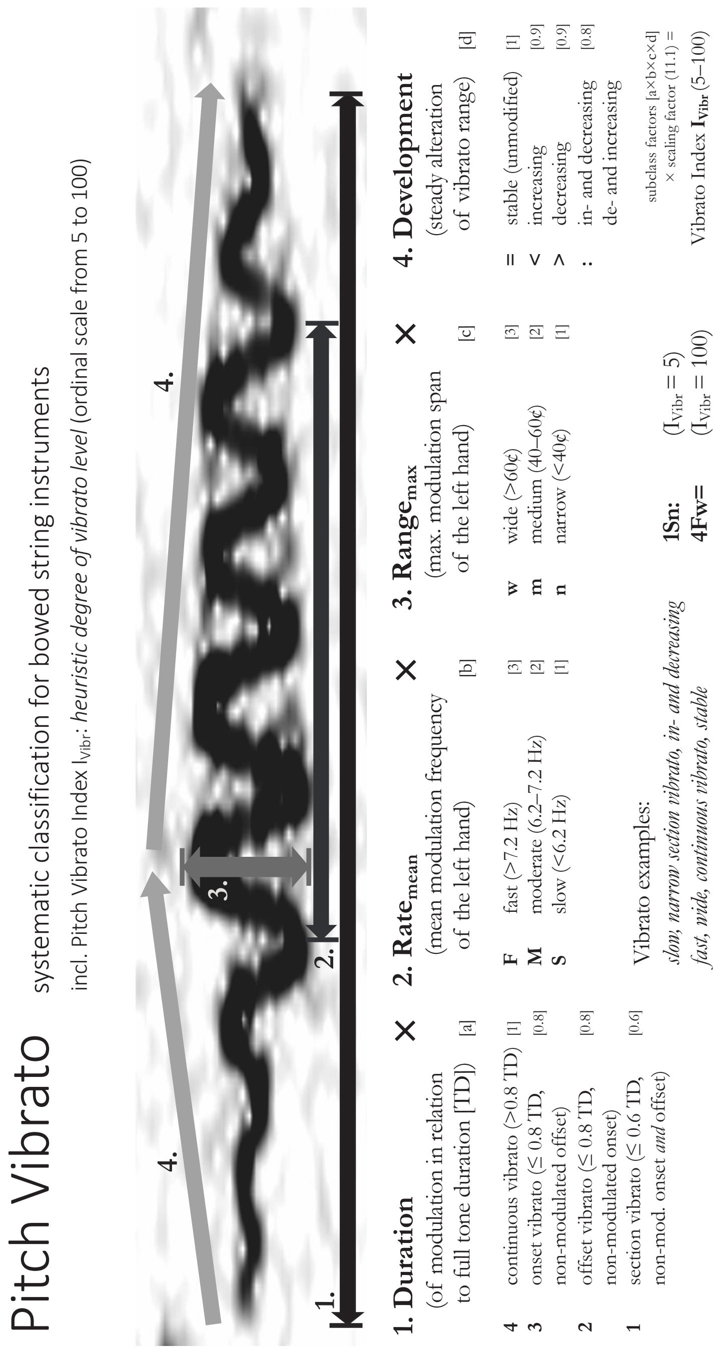


Figure 2.1: Pitch Vibrato
Systematic classification for bowed string instruments

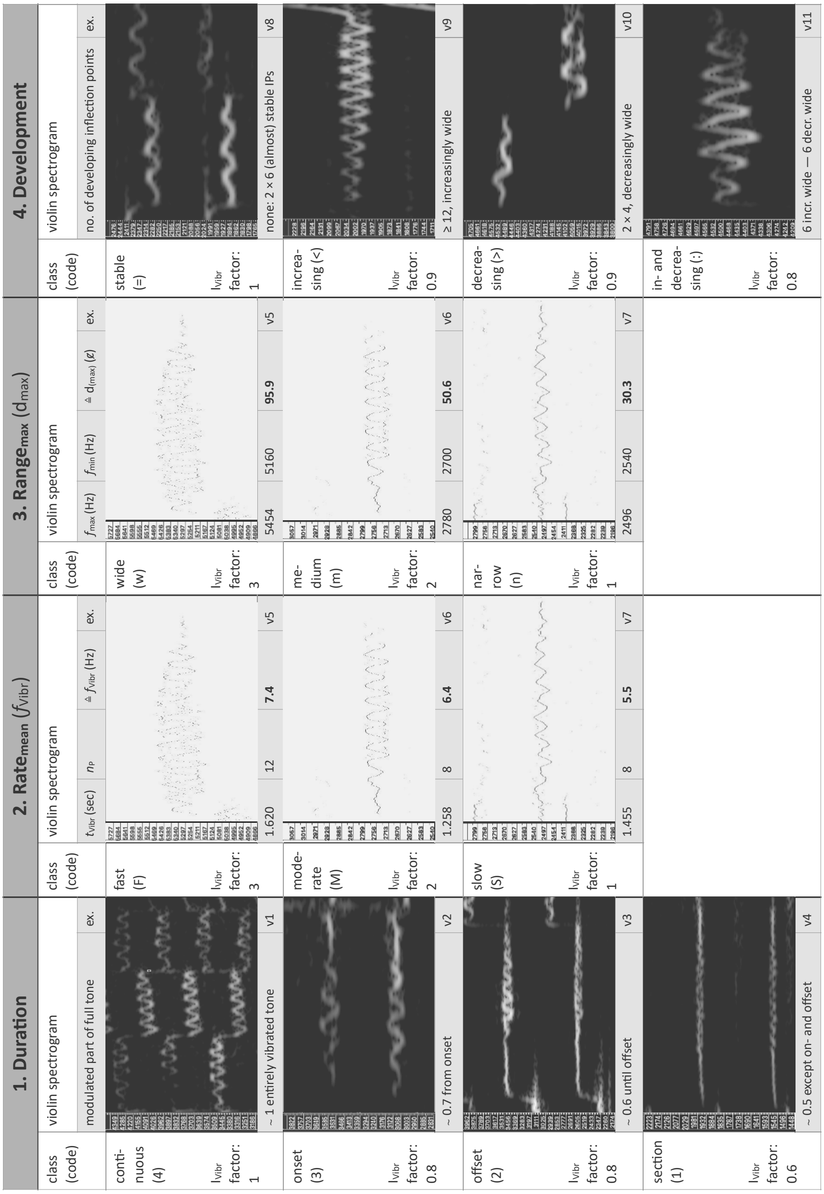


FIGURE 2.2: Examples of Pitch Vibrato Subclasses
Determination based on spectrograms
x-axes: time in sec; y-axes: frequency in Hz
(various linear scales: c. 1,400–6,000 Hz)

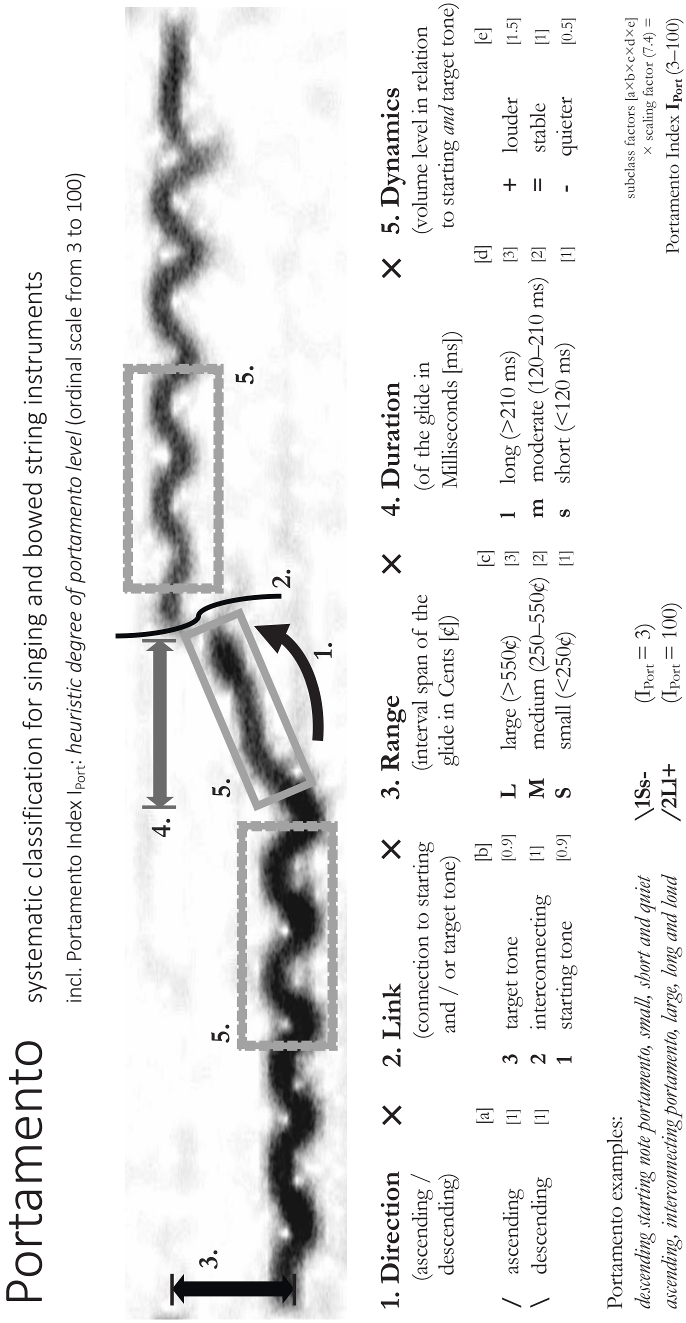
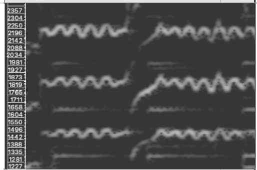
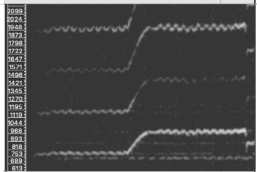
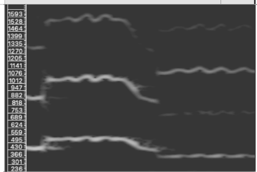
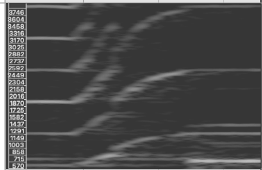
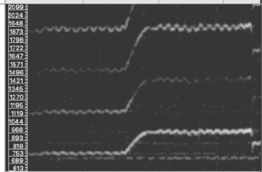
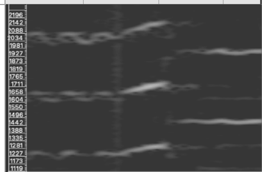
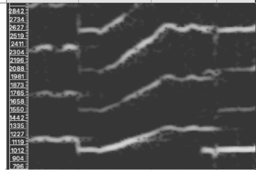
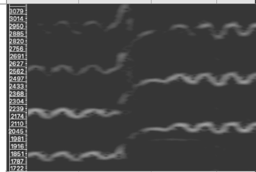
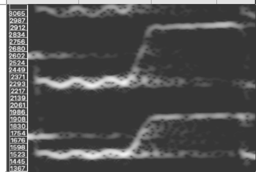


FIGURE 3.1: Portamento
Classification for singing and bowed string instruments

1.–2. Direction / Link		
class (code)	violin spectrogram: glide direction, connected to	ex.
ascen-ding (/), target (3) I_{Port} factor: 0.9	 ascending, target tone	p1
asc. (/), inter-connec-ting (2) I_{Port} factor: 1	 asc., both starting and target tone	p2
descen-ding (\), starting (1) I_{Port} factor: 0.9	 descending, starting tone	p3

3. Range					
class (code)	violin spectrogram	f_{start} (Hz)	f_{end} (Hz)	≙ d (¢)	ex.
large (L) I_{Port} factor: 3		1311	2623	**1201**	p4
me-dium (M) I_{Port} factor: 2		1777	2215	**382**	p2
small (S) I_{Port} factor: 1		1663	1727	**65**	p5

4. Duration					
class (code)	violin spectrogram	t_{start} (s)	t_{end} (s)	≙ t_{Δ} (ms)	ex.
long (l) I_{Port} factor: 3		6.222	6.548	**326**	p6
mo-derate (m) I_{Port} factor: 2		3.947	4.121	**174**	p7
short (s) I_{Port} factor: 1		4.167	4.249	**82**	p8

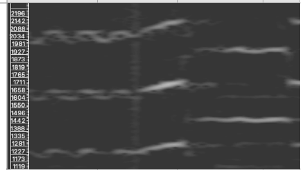
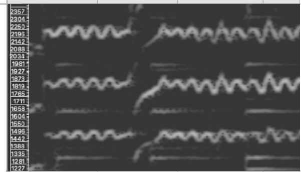
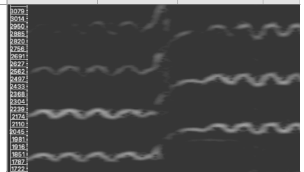
5. Dynamics					
class (code)	violin spectrogram	offset level starting tone	onset level target tone	max. level portamento	ex.
louder (+) I_{Port} factor: 1.5		-24 dBFS	-27 dBFS	-17 dBFS	p5
stable (=) I_{Port} factor: 1		-20 dBFS	-21 dBFS	-20 dBFS	p1
quieter (-) I_{Port} factor: 0.5		-20 dBFS	-23 dBFS	-27 dBFS	p7

FIGURE 3.2: Examples for Portamento Subclasses
Determination based on spectrograms
x-axes: time in sec; y-axes: frequency in Hz
(various linear scales: c. 200–3,800 Hz)

1.2 Pitch Vibrato

Vibrato is defined here as *intended pitch oscillation*, following Carl Seashore and his colleagues' distinction between pitch, volume, and timbre vibrato,[39] which still seems to correspond to the current state of research.[40] In violin performance practice, this expressive means is executed by the left hand which causes a periodical modulation in pitch.[41] Thus, most authors understood pitch vibrato as a sinusoidal waveform with a defined vibrato *rate* and *range*, corresponding to the left hand's speed (usually given in Hertz (Hz): vibrations per second) and deflection (understood as the pitch frequency difference between the minimum and maximum inflection points, given in semitones or a frequency range in cents). More recently, software-based research performed detailed examinations on historical vibrato rates and ranges: For instance, Daniel Leech-Wilkinson carried out extensive measurements on changing attitudes towards violin vibrato in selected recordings from the beginning to the end of the 20th century, using spectrogram software predating the SV;[42] furthermore, Tilo Hähnel conducted extensive studies on early recorded vibrato in singing (1900–1930) by making use of pitch detector plugins in SV and an earlier version of his script *Vibratoanalyse.R*.[43]

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39 See Carl Emil Seashore (Ed.), *The Vibrato* (Studies in the Psychology of Music 1), Iowa 1932; ibid., *Psychology of the Vibrato in Voice and Instrument* (Studies in the Psychology of Music 3), Iowa 1936.

40 See, e.g., the adoption of Seashore's concepts in Tilo Hähnel / Karin Martensen, "How Thomas A. Edison shaped today's singing ideal: Tracking his ambiguous concept of tremolo by analysing archival documents and sound recordings", in: *Empirical Musicology Review* 28/1–2 (2019), pp. 22–49, here pp. 29f., DOI: 10.18061/emr.v14i1-2.6689.

41 Other than, e.g., the most common understanding of the terms "bow vibrato" or *ondeggiando*, which rather answers to volume vibrato (or *tremolo*) produced by short-term increasing and decreasing bow stiction. In singing, this roughly corresponds to changing tension of the vocal folds (pitch vibrato) versus changing air stream pressure (volume vibrato).

42 See Daniel Leech-Wilkinson, "Early recorded violin playing: evidence for what?", in: *Spielpraxis der Saiteninstrumente in der Romantik. Bericht des Symposiums Bern, 18.–19. November 2006* (Musikforschung der Hochschule der Künste Bern 3), ed. by Claudio Bacciagaluppi et al., Schliengen 2011, pp. 9–22, esp. tables 1 and 2 on pp. 16 and 19. In a personal email, Leech Wilkinson stated that the measurements were undertaken in or before 2006 by making use of a software called *Spectrogram*.

43 See, e.g., Hähnel / Martensen, "How Thomas A. Edison shaped today's singing ideal" (note 40); Tilo Hähnel, "On the Quantification of the Diva. Vibrato, Ornamentation, Glissando, Tempo and Register in Acoustical Recordings between 1900 and 1930", in: *Technologies of Singing – Proceedings of the International Conference Detmold 2018* (Technologien des Singens 3), ed. by Rebecca Grotjahn, Malte Kob, and Karin Martensen [forthcoming]; as well as Hähnel, "Automatisierte Vibratoanalyse" (note 3).

However, vibrato also comprises an aspect of rate and range *development*, which for historical reasons seems worth a closer look: authors reported onset and offset qualities as well as increasing and decreasing vibratos for centuries. Moreover, they used detailed visualisations to typify the complex matter of vibrato as a highly flexible means of expression, as can be seen in FIGURE 2.3. As early as the late 1690s, Roger North reported a "gentle and slow wavering […] upon the swelling the note".[44] From his sketch (see FIGURE 2.3, "1") it becomes apparent that the vibratos he witnessed started with some delay after tone onset and lasted for only a section of the tone; therefore, they served as an embellishment rather than as a constant condition. Moreover, the vibratos consisted of different rates (speeds) and ranges (levels) of volume alteration, which after onset developed independently (see North's second example) or reciprocally (third example: if the rate accelerates, the range conversely narrows).

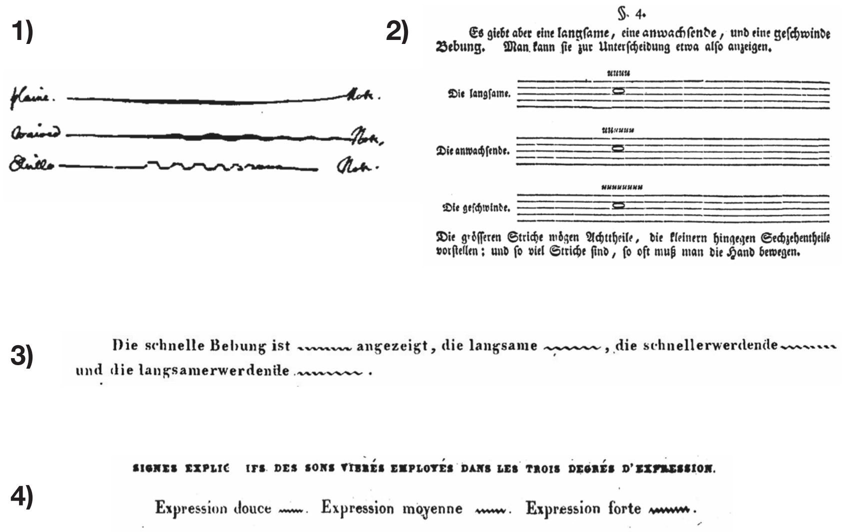

FIGURE 2.3: Early Vibrato Visualisations
1) North's essays on music (late 1690s) and in violin schools by 2) Leopold Mozart (1787), 3) Louis Spohr [1832/33], 4) Charles-Auguste de Bériot [1857/58][45]

[44] Roger North, *Roger North on music. Being a selection from his essays written during the years c. 1695–1728*, ed. by John Wilson, London 1959, p. 18. Although North seems to refer to volume vibrato rather than to pitch vibrato here, these qualities seem to be transferable in the light of the sources quoted later.

[45] Ibid., pp. 20f.; Mozart, *Gründliche Violinschule* (note 25), p. 244; Louis Spohr, *Violinschule*, Wien: Haslinger n. d. [1832/33], plate no. T. H. 6050, p. 176; de Bériot, *Méthode de Violon*, vol. 3 (note 14), p. 120.

In 1787, Leopold Mozart reported a "Tremolo" (or "Tremoleto" or "Bebung") in singing but described its imitation on the violin as a form of pitch vibrato.[46] Subsequently, he distinguished between a "slow", an "increasing", and a "fast" vibrato. He depicted various vibrations with "u"-like signs (see FIGURE 2.3, "2") getting smaller when increasing in number, which implies that *faster* comes along with *narrower*.[47] Louis Spohr, in his violin school of c. 1833, similarly distinguished between four different pitch vibrato types depending on vibrato rate (speed) and its development. Moreover, he drafted specific notation signs for each (see FIGURE 2.3, "3"), depicting (1) a fast vibrato to be used for strongly emphasised notes, (2) a slow vibrato for measured notes in passionate melodies, (3) a vibrato that starts slow and accelerates to intensify long notes, and (4) a vibrato that starts fast and decelerates to abate long notes. Furthermore, Spohr demanded the accelerations and decelerations to be executed relatively smooth and not just as abrupt changes of speed.[48]

Almost concurrently, Spohr's French colleague Pierre Baillot favoured vibrato for a section of the note only: He stated that in order to avoid "suffering of the ear", it is "necessary to begin and end by making the just and pure tone heard".[49] Several years later, Charles de Bériot seemed to differentiate predominantly between various pitch *ranges* (as opposed to Spohr)[50] corresponding to various "degrees of expression", and distinguished between "soft", "medium", and "strong" vibrato types[51] (see FIGURE 2.3, "4"). By the middle of the 20th century, the growing variety of types and approaches was reflected in numerous writings and exercise books solely on the phenomenon of vibrato. Béla Szigeti for instance,[52] in his treatise *Das Vibrato, seine Bedeutung und seine Lehrbarkeit* (1950), differentiated not only between a number of main vibrato classes and a multitude of subclasses (with four training variations for the class of "Dauervibrato" –

46 Mozart, *Gründliche Violinschule* (note 25), p. 243 ("Das elfte Hauptstück", §1 and §2). According to Mozart, when imitated on bowed string instruments, "tremolo" is to be executed as movement of the left hand in the direction of the bridge and back to the scroll (§2).

47 Ibid., p. 244 (§4).

48 Cf. Spohr, *Violinschule* (note 45), p. 175.

49 Original wording: "Pour que l'oreille n'en souffre point et en soit aussitôt console il faut commencer et finir par faire entendre le ton juste et pur"; Pierre Baillot, *L'Art du Violon. Nouvelle Méthode*, Mainz / Antwerp: Schott n. d. [1835, French and German edition, first edition: c. 1834], plate no. 4260, p. 133 (my translations).

50 This might point to 19th century vibrato idiosyncrasies in France as opposed to Germany – whereas the former indicated heightened expression via increasing vibrato *ranges*, the latter might have preferred changes in vibrato *rate* instead. However, this hypothesis demands further examination.

51 De Bériot, *Méthode de Violon*, vol. 3 (note 14), p. 120.

52 Hungarian violinist (1894–1975), violin pedagogue in Milano and Zürich, not to be confused with his well-known compatriot Joseph Szigeti (1892–1973).

"continuous vibrato"), but also introduced the type "crescendierendes Vibrato" ("increasing vibrato"). Moreover, he advocated for a historical awareness in linking different vibrato types to different musical epochs, and emphatically warned against the copying of other violinists' personal vibrato styles.[53]

A comprehensive vibrato classification should take into account the great variety of vibrato types considered here, each of which entailing potentially diverging, aesthetic implications. However, the sheer number of different types calls for a reduction to a few main classes. Therefore, pitch vibrato shall be understood as comprising four components: (1) *duration* of the vibrated section in relation to the full tone, (2) mean vibrato *rate* (speed) and (3) maximum vibrato *range* (span); finally, (4) consistent *range development* over consecutive vibrato periods. The resulting classification, given in FIGURE 2.1, is again supplemented by an overview of exemplary vibrato appearances in spectrogram view (see FIGURE 2.2, p. 211, and attendant sound examples).

(1) Duration

A vibrated section shall be defined as a number of consecutive sinusoidal oscillations of pitch. To compensate for potential wow and flutter and other transfer instabilities (particularly apparent in many historical recordings), a threshold of ≈10 cents is recommended. Vibratos above that may then be classified by relating their duration to the duration of the full tone:

- **continuous** (code "4"): vibrato lasts for >0.8 (80%) full tone duration; *spectral appearance:* pitch oscillation is evident for (almost) the full tone
- **onset** (code "3"): vibrato lasts for ≤0.8 full tone duration starting from tone onset, non-vibrated offset; *spectral appearance:* pitch oscillation from the beginning of the tone, no oscillation at the end of the tone
- **offset** (code "2"): vibrato lasts for ≤0.8 full tone duration until tone offset; non-vibrated onset; *spectral appearance:* stable pitch at the beginning, oscillation at the end of a tone
- **section** (code "1"): vibrato lasts for ≤0.6 full tone duration; non-vibrated tone onset and offset; *spectral appearance:* stable pitch at the beginning and at the end, temporary oscillation in between

(2) Mean Rate

The mean rate (speed) of a vibrato in Hertz is defined as the number of vibrato periods per second. In spectrogram view, this may be determined

[53] Béla Szigeti, *Das Vibrato, seine Bedeutung und seine Lehrbarkeit* [tr. "The vibrato, its significance, and its teachability"], Zürich 1950, pp. 28–32 and 36f.

by counting from the first upper inflection point to the last upper inflection point. The respective time values can be taken from the data of the corresponding FFT windows. To obtain a fine time resolution in the spectrogram, choose FFT window sizes as short as possible but large enough to distinguish the vibrato onset from other frequencies' onsets.[54] In SV, point to the respective windows (the little frames that appear when hovering over the spectrogram with the navigator tool, the 'hand'), then take the time stamp from the dialogue box (upper right corner of the pane) and calculate the averages. The mean rate may then be calculated by

$$\frac{x}{t_2 - t_1}$$

where x is the number vibrato periods, t_1 is the time stamp of the first inflection point, and t_2 is the time stamp of the last one (in seconds).[55] The resulting rates may then be classified as follows:

- **fast** (code "F"): vibrato rate of >7.2 Hz; *spectral appearance* (relative indication – strongly depends on horizontal zoom level): densely packed 'hills and valleys'
- **moderate** (code "M"): vibrato rate from 6.2 to 7.2 Hz; *spectral appearance:* modest space between 'hills and valleys'
- **slow** (code "S"): vibrato rate of <6.2 Hz; *spectral appearance:* significant space between 'hills and valleys'

The respective boundary values for both the rate and range subclasses have been determined based on Leech-Wilkinson's large-scale measurements of a selection of 100 years of recorded violin performances (50 recordings of 27 violinists, dating between 1902 and 2002); they represent the respective upper (7.2 Hz / 60 ¢) and the lower (6.2 Hz / 40 ¢) terciles of the data.[56]

(3) Maximum Range

Vibrato range (span) shall be measured at its maximum deflection to provide an ending point for potential range development. The range is calcu-

54 Cf., e.g., Vollmer, "Preparing Spectrograms" (note 7), esp. pp. 100–103. Given a sampling rate of 44.1 kHz, an adequate window size for vibrato rate measurements in SONIC VISUALISER would be 256.

55 In an Excel template, this formula may be coded as "=A1/(B1-C1)", where cell A1 contains x, B1 contains t_2, and C1 contains t_1.

56 See Leech-Wilkinson, "Early recorded violin playing" (note 42), esp. Tables 1 and 2 on pp. 16 and 19. In Leech-Wilkinson's results, the vibrato rate median is at 6.7 Hz, its range median is at 50 ¢ (rate and range are called "speed" and "depth" by the author), and the standard deviation is at 0.5 Hz and 11 ¢, respectively.

lated by determining the pitch difference between the upper and lower inflection points (in Hz), which is then converted into a value on the cent scale (¢, where 100 ¢ equals one semitone).

To do so, choose a medium FFT window size that delivers a relatively high frequency resolution and at the same time does not disregard temporary frequency peaks.[57] To avoid distortion by outbursts, aim for ending points of relatively homogenous developments rather than single maxima within a number of otherwise uniform periods. To compensate for measurement errors due to FFT's uncertainty principle, choose the highest possible overtones of the period in question – to identify them, utilise SV's measure tool (the compass-like icon in the toolbar). Following this, switch to the navigator tool (the 'hand'), point to the maximum and minimum within the overtone's largest deflection, and calculate averages of their "Bin Frequency" values given in the dialogue box. An even better alternative may be to use SV's "Frequencies" bin option, which estimates and visualises a single 'core frequency' based on peak levels;[58] it may reduce the potential range of measurement errors remarkably. Convert the gathered values to cent scale by the formula

$$1200 \times log_2(\frac{f_{max}}{f_{min}})$$

where f_{max} is the maximum's frequency and f_{min} the minimum's frequency in Hertz.[59] Because of the FFT uncertainties in representing sawtooth waves (such as of bowed string instruments) as well as in time-frequency discrimination, these frequency measurements are subject to significant tolerances.[60] Furthermore, SV's "Frequency" bin option may slightly even out maxima and minima, so an additional tolerance of around 10 cents should be considered. However, due to the lack of alternatives, this approach currently yields the best estimates, but the measurement results should be given together with corresponding tolerance indications.

The following indicates the *Range* subclasses based on frequency spans in cents. As mentioned above, the boundary values were determined on base of Leech-Wilkinson's measurements.[61]

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57 Cf. Vollmer, "Preparing Spectrograms" (note 7); esp. pp. 100–103. Given a sampling rate of 44.1 kHz, an adequate window size for range measurements in SV would be 2,048, which allows for a tolerance of ±48 ms and ±21.53 Hz.

58 See ibid., pp. 102f.

59 Convenient Excel formula: "=1200*LOG((A1/B1);2)", where cell A1 contains f_{max} and B1 contains f_{min}.

60 See Hermann Gottschewski's objection (note 9) as well as the tolerance indications in Vollmer, "Preparing Spectrograms" (note 7), p. 109, TABLE 1.

61 Corresponding to the upper (60 ¢) and lower (40 ¢) tercile of Leech-Wilkinson's data; cf. note 56.

- **wide** (code “w”): vibrato range maximum of >60 cents (¢);
  spectral appearance (strongly depends on vertical zoom level): high ‘hills’, deep ‘valleys’

- **medium** (code “m”): vibrato range maximum of 40–60 ¢;
  spectral appearance: moderate ‘hills and valleys’

- **narrow** (code “n”): vibrato range maximum of <40 ¢;
  spectral appearance: flat ‘hills and valleys’

(4) Development

As paraphrased above, authors such as Louis Spohr described vibratos that intensify by increasing the vibrato rate (speed) rather than the range. However, large-scale measurements on early to mid 20th century recordings (57 productions of Beethoven’s Violin Concerto Op. 61, dating from 1912 to 1956) have shown that most of the violinists developed their vibratos in *range*, not in rate – that is, by widening or narrowing the vibrato span instead of getting faster or slower, as favoured by violinists such as de Bériot.[62] Moreover, in most cases, an inverse proportionality applies: If the range increases in span, the rate becomes slower and vice versa, just as Leopold Mozart already implied in 1787.[63]

Because of these correlations (and to avoid an endless number of subclasses), vibrato development is pragmatically classified by consistent increases or decreases in range only. A “consistent development” applies to vibratos of a steady growth in one direction (increasing / decreasing) over at least three inflection points (or one and a half periods), so that potentially unintended outliers will be neglected. Thus, *Range Development* is differentiated as follows:

- **stable** (code “=”): number of consecutive inflection points (CIPs) consistently developing in range amounts to <3;
  spectral appearance: vibrato periods (almost) uniform in range

- **increasing** (code “<”): >3 consistently increasing CIPs;
  spectral appearance: vibrato periods uniformly become larger

- **decreasing** (code “>”): >3 consistently decreasing CIPs;
  spectral appearance: vibrato periods uniformly become smaller

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62 Recordings comprised 47 different violinists born between 1873 and 1933 (12 women, 35 men). Few exceptions apply to violinists of the intermediate generations, such as Bronisław Huberman (1882–1947) or Joseph Szigeti (1892–1973). Publication of this study forthcoming.

63 Exceptions are cases of very strong intensification, when both range *and* rate increase at the same time. See, e.g., the “increasing” example in FIGURE 2.2 (Huberman 1934 immediately prior to an intense melodic tenth leap, SOUND EX. V9).

- **increasing and decreasing (or the inverse)** (code ":"): >3 consistently increasing CIPs, followed by >3 consistently decreasing CIPs (or vice versa); *spectral appearance:* vibrato periods uniformly become larger first, then smaller

2.3 Portamento

Portamento is understood here as an *intended glide of pitch*, both at the beginning or the end of a note or to connect two notes. Following the approach of Carl Flesch (1929), it should be distinguished from the term *glissando,* which would refer to rather unintended or enforced pitch glides due to position changes.[64] Unlike vibrato, portamento in violin performance relies on the interaction of both the left hand (pitch) and the bow (onset, duration and volume); hence, the number of factors involved in the resulting sound seems endless. Working out a selection of the potentially most impactful by consulting the historical sources thus seems promising again.

In his 1802/03 violin school, Michel Woldemar gave a detailed account of the Italian virtuoso Nicola Mestrino's (1748–1789) early art of portamento (see FIGURE 3.3, "1"):[65] "Of the style of Mestrino [to glide] from one tone to another by means of enharmonic or quarter tones. All of them are to be executed with one finger", followed by an exemplary exercise. Woldemar notated fast, uninterrupted glides in the style of grace notes for dotted melodies in both upward and downward directions. These appear supported by fingerings and indication signs for dynamics: *crescendo* for upward glides, *decrescendo* for downward glides. At least four crucial aspects are entailed here already: 1) reasonable gliding opportunities, 2) gliding speed, 3) fingering – that is, the question of interrupted or uninterrupted glides, and 4) dynamics. A similar account was given by Pierre Baillot (1834/35) who notated upward portamentos together with a *crescendo* and with a *decrescendo* in reverse. His fingerings, however, indicate a finger switch during the glide, which (other than in Woldemar's account) comes along with a little melodic 'gap' at the beginning. Furthermore, the choice of target finger seems to depend on pitch difference (or, rather: the distance of position change) between starting and target note.[66] Louis Spohr (1833), by contrast, favoured a fast (and almost imperceptible) glide of the *starting* finger with a 'finger switch gap' at its end (see FIGURE 3.3, "2"); otherwise, as he put it, the portamento would degenerate into an "unpleasant howling".[67]

64 Flesch, *Die Kunst des Violinspiels* (note 16), p. 16.

65 Michel Woldemar, *Grande Méthode*, Paris: Hanry [1802/03], p. 43 (my translations).

66 Baillot, *L'Art du Violon* (note 49), p. 70.

67 Spohr, *Violinschule* (note 48), pp. 120–126, esp. pp. 120, 126. Spohr names one exception of this rule: If the target note is played in *flageolet*, the glide may be executed from one and the same finger all the way from starting to target note.

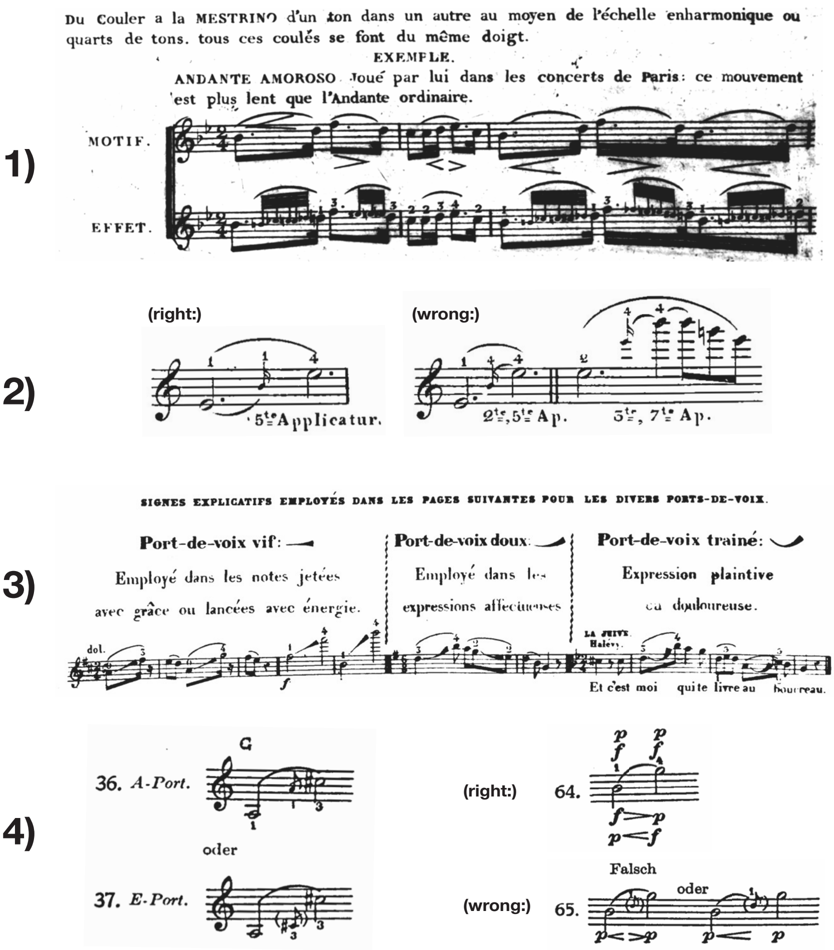

FIGURE 3.3: Early Portamento Visualisations
in violin schools by 1) Woldemar [1802/03], 2) Spohr [1833],
3) de Bériot [1857/58], and 4) Flesch (1923/29)[68]

Arguably, the most ambitious approach to visualise portamentos has been presented by Charles-Auguste de Bériot (1857/58), who introduced specific portamento signs in his violin school (see FIGURE 3.3, "3"): These marks seem to indicate pitch and / or speed through flection of the curve; dynamics, as is apparent from the following exercises, are indicated by supporting *crescendo* and *decrescendo* signs (although the opening right end

68 Ibid., p. 43; Spohr, *Violinschule* (note 45), p. 120; de Bériot, *Méthode de Violon*, vol. 3 (note 14), p. 215; Flesch, *Die Kunst des Violinspiels* (note 16), pp. 18 and 21.

of each portamento sign suggests that *each* portamento would entail a *crescendo*). Although these signs were apt to carry significant information, they have never been established on a broader base within musical notation.[69] However, the importance of direction, range, speed, and dynamics to describe portamentos becomes apparent again in the ideas of de Bériot.

Finally, Carl Flesch (1929) dedicated considerable lengths of his violin school to a meticulous analysis of the technical execution as well as the aesthetic implications of portamento.[70] As done by the authors before him, he distinguished three main portamento types based on fingering: an "A-Portamento", executed by the starting finger; an "E-Portamento", executed by the target finger – both of them would leave a little 'gap' during the glide; and a "fantasy portamento", which in its most frequent form would entail a 'silent switch' from the starting to the target finger, resulting in an almost imperceptible though uninterrupted portamento.[71] Besides that, Flesch – as most authors before him – emphasised the importance of portamento for a tasteful and natural interpretation but empathically warned against its overuse; generally, he advocated for predominantly incidental portamentos, both fast and quiet. This again points to the aspects of portamento duration (speed) and loudness; moreover, Flesch explicitly distinguished between a "right" execution, which follows the dynamics of both the starting and ending note, and a "wrong" one that stands out by a dynamical swell (see FIGURE 3.3, "4").

More recent research has presented some attempts to trace and differentiate various historical portamento types.[72] As far as sound visualisation

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69 De Bériot, *Méthode de Violon*, vol. 3 (note 14), pp. 215–219. So far, I have not found any written music (not even instructive editions) that adopted or refined this approach.

70 Flesch, *Die Kunst des Violinspiels* (note 16), pp. 17–22. The aesthetic implications of portamento usage concerned Flesch to such an extent that he drafted an extensive chapter on the "question of portamento" within a monumental book on violin fingering. The book's unfinished typoscript became posthumously published as Carl Flesch, *Die Hohe Schule des Fingersatzes*, ed. by Kathinka Rebling, Frankfurt a. M. 1995 [Reprint: Berlin 2013].

71 Flesch, *Die Kunst des Violinspiels* (note 16), pp. 18 and 21. "A" and "E" refer to the German words "Anfangs-" und "End-" (beginning and ending). In the English translation of Flesch's school, *The Art of Violin Playing*, tr. by Frederick H. Martens, Boston 1924, ^{2}1939, the same types are named "B-" and "L-portamento". Since this edition was a later publication compared to the German first publication [1923], the original designation is taken here.

72 See, e.g., David Milsom, *Theory and practice in late nineteenth-century violin performance: an examination of style in performance, 1850–1900*, Ashgate 2003, esp. pp. 76–110; John Potter, "Beggar at the Door: The Rise and Fall of Portamento in Singing", in: *Music & Letters* 87/4 (2006), pp. 523–550; Camilla Bork, "Between music and noise. The discussion of portamento and its socio-aesthetic implications

[type + respective pitch intervals]	[execution on bowed string instruments]
Slow Portamento (small intervals up to a fourth)	glide with one finger
Fast Portamento (large intervals from a fifth)	glide with two different fingers (Spohr prefers starting over target finger)
Intonazione (small intervals)	glide at the beginning of a phrase (with target finger)
Cercar della nota (small intervalls)	glide *after* bow change (with target finger)
Anticipazione della nota (small and large intervals)	glide *before* bow change (with target finger)
Vibrar la voce (small intervals)	finger switch at the same tone [two consecutive notes of equal pitch]

TABLE: Portamento Techniques in bowed string instrument and singing practices after Köpp (2015)[73]

is concerned, Kai Köpp's approach is of particular interest: In 2015, he pointed to the lack of precise information in written sources on finger speed, bow changes, and dynamic development, proposing that (spectrograms of) early recordings may better help with the reconstruction of period portamento practices.[74] As a striking result of his survey, Köpp presented a tabulation of six historical "portamento techniques in bowed string instrument and singing practices" (see TABLE above): the first two categories ("slow" and "fast" portamento) depend on speed and pitch intervals, the remaining four refer to phrasing and pitch intervals. All of them are complemented by information on technical execution.

The importance of range, duration and loudness for the perception of glides has been emphasised by research in the field of psychoacoustics as well.[75] In addition, Kilian Sprau most recently identified the aspects of dy-

during the long nineteenth century", in: *Investigating Musical Performance. Theoretical Models and Intersections*, ed. by Gianmario Borio et al., London / New York 2020, pp. 139–157.

73 Kai Köpp, "Die hohe Schule des 'Portamento'. Violintechnik als Schlüssel für die Gesangspraxis im 19. Jahrhundert", in: *Dissonance* 132 (2015), pp. 16–25, here p. 22, DOI: 10.24451/arbor.6952 (my translations); quotation marks ("Fortgleiten", "Fingerwechsel auf dem gleichen Ton") omitted. In his article, Köpp named the last portamento type "Librar la voce"; however, in a private conversation in February 2020, he corrected the term to "Vibrar la voce", which has been adapted here.

74 Köpp, "Die hohe Schule des 'Portamento'" (note 72), esp. p. 19.

75 See Johan t'Hart / René Collier / Antonie Cohen, *A perceptual study of intonation: an experimental-phonetic approach to speech melody*, Cambridge 1990,

namics, speed, diastematics (compass or pitch curve, respectively) and timbre as crucial factors for the "prominence" of a glide.[76] It therefore seems reasonable to take up these elements and complement them by aspects which seemed to be essential for the authors of the violin schools quoted above. Sprau's suggestion to consider timbre, however, is not taken into account here, since the impact of early recording technologies arguably was too great to preserve original timbre qualities for historical research.[77] Furthermore, Portamento *speed* (which is a function of range and duration) and aspects of acceleration or deceleration (that are apparent from de Bériots account, see the "doux" and "trainé" signs) are considered only indirectly. Portamento, then, is understood as comprising five central elements: (1) direction, (2) type of link to its surrounding tones, (3) pitch range, (4) glide duration, and (5) volume level compared to its surrounding tones.
The classification overview and respective subclass examples are given in FIGURES 3.1 and 3.2 (pp. 212f.). To determine the subclasses in SV's spectrogram view, the same settings as for articulation are recommended (see above, note 33).

(1) Direction

Considering the violinists quoted, the direction of a glide may have a significant impact on the further qualities of the portamento. Moreover, since it does not need to depend on both the pitches of the starting *and* the target note, glide direction is not necessarily prescribed by the score (consider the case of "Vibrar" portamentos between two notes of equal pitch; see the TABLE on p. 224). A distinction is made between two classes:

- **ascending** (code "/"): portamento increases in pitch; *spectral appearance:* glide in upward direction
- **descending** (code "\"): portamento decreases in pitch; *spectral appearance:* glide in downward direction

esp. pp. 25–35; Emery Schubert / Joe Wolfe, "The rise of fixed pitch systems and the slide of continuous pitch: A note for emotion in music research about portamento", in: *Journal of Interdisciplinary Music Studies* 7/1–2 (2013), pp. 1–28, esp. pp. 2–4.

76 See Kilian Sprau's contribution to this volume: "Ästhetische Relevanz zwischen Hören und Messen", pp. 245–267, here pp. 252f (my translations).

77 See Malte Kob / Tobias A. Weege, "How to Interprete [sic] Early Recordings? Artefacts and Resonances in Recording and Reproduction of Singing Voices", in: *Computational Phonogram Archiving* (Current Research in Systematic Musicology 5), ed. by Rolf Bader, Cham 2019, pp. 335–350; Frithjof Vollmer / Boris-Alexander Bolles, "In Search of the 'Phonograph Effect': Expressive sound gestures in violin performance and their modification by early recording and reproduction devices (1901–1933)" [forthcoming].

In the special case of portamentos that change their direction during the glide (such as indicated by de Bériots "trainé" signs, see FIGURE 3.3, "3"), the direction with higher values in terms of pitch difference decides.

(2) Link

The *Link* subclass indicates the type of connection of a portamento to its starting and target tones. Taking into account Woldemar, Baillot, Spohr, and Flesch, it expresses the position of small 'gaps' within the glide due to a vocalist's breathing breaks or to a string instrumentalist's finger switches and bow changes.

- **target** (code "3"): portamento is linked to the target tone; *spectral appearance:* little gap between starting tone and glide
- **interconnecting** (code "2"): portamento is linked to both starting and target tones, either uninterrupted or with a small break within the glide (finger switch while gliding, see Flesch's "fantasy portamento"); *spectral appearance:* little gap *during* the glide or no gap whatsoever
- **starting** (code "1"): portamento is linked to the starting tone; *spectral appearance:* little gap between glide and target tone

(3) Range

The *Range* subclass indicates the span between the portamento's starting and ending pitches in cents, following Köpp's basic distinction between portamentos with an interval range of up to a fourth and those from a fifth onwards (see TABLE on p. 224). To refine the grid, the former has been split to differentiate between glides of up to a major second and those of up to an augmented fourth. To determine pitch ranges in SV's spectrogram view, switch to the "Frequencies" bin option,[78] choose the navigator tool (the 'hand') and point to the starting and ending point of the glide. The respective pitch frequencies in Hertz are given in SV's dialogue box in the upper right corner of the pane. Their difference in cents may then be calculated with the help of the same formula used for vibrato ranges (see pp. 218ff).

To compensate for variance in tuning, the corresponding interval indications are defined with a tolerance of ± 50 cents around their nominal range in equal-tempered scale (e.g., a minor third is understood as every instance between 250 and 350 cents):

- **large** (code "L"): portamento exceeds a pitch range of 550 cents (corresponding to a glide larger than a fourth); *spectral appearance:* large glide between starting and ending point

[78] Cf. vibrato "range" subclass, pp. 218ff. For objections against this approach, see Vollmer, "Preparing Spectrograms" (note 7), pp. 106f., 112.

- **medium** (code "M"): portamento's pitch range is between 250 and 550 cents (corresponding to a minor third to a fourth); *spectral appearance:* medium glide between starting and ending point

- **small** (code "S"): portamento's pitch range is smaller than 250 cents (corresponding to minor and major seconds); *spectral appearance:* small glide between starting and ending point

(4) Duration

Portamento duration is measured in absolute values. To do so in SV, switch to the "Frequencies" bin option and choose FFT window sizes as short as possible but large enough to clearly identify the glide's starting and ending points.[79] Connect these points with the help of the Select tool (the 'cursor') and gather the glide's duration from the brackets at the top of the window (first value).[80]

Based on a study of 20th century vocal recordings, Daniel Leech-Wilkinson assumed a range from 50 to 300 milliseconds (ms) for "swoops" (that is, target tone glides), whereas "most instances in singing will be between 100 and 200 ms".[81] Measurements on 20th century violin recordings showed that portamento-related glides at least in classical violin performance ranged in the same area and exceeded 300 ms only in exceptional cases.[82] Therefore, typical durations here are expected to last from 30 ms

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79 Given a sampling rate of 44.1 kHz, an adequate window size would be 256, which allows for a tolerance of only ±6 milliseconds.

80 Some authors stated that it would be "difficult" or even "impossible" to measure the duration of a portamento when combined with vibrato, since the starting and ending point of the glide may not be clearly identifiable (see, e.g., Nicholas Cook / Daniel Leech-Wilkinson, "A musicologist's guide to Sonic Visualiser", https://charm.rhul.ac.uk/analysing/p9_1.html, 24.02.2022; Daniel Leech-Wilkinson, "Portamento and Musical Meaning", in: *The Journal of Musicological Research* 25 (2006), pp. 233–261, esp. p. 236; as well as Sprau, "Ästhetische Relevanz zwischen Hören und Messen" (note 76), pp. 253f.). However, this may be not as problematic as suggested, since each vibrato oscillates around a (moving) pitch average which can be calculated from the vibrato's inflection points (or simply estimated based on what is seen in spectrogram view). Following that, a glide is apparent as soon as this average starts to move continuously towards one direction (with a minimum of speed and range, corresponding to the thresholds given above); the beginning and end of this continuous movement then equals the starting and ending points of the glide.

81 Leech-Wilkinson, "Portamento and Musical Meaning" (note 80), p. 236.

82 These results will be discussed as part of my forthcoming dissertation on changing tastes in early 20th century string performance.

(perception threshold according to Leech-Wilkinson)[83] up to 300 ms. Dividing this range in three equal parts then leads to the following duration subclasses:

- **long** (code "l"): portamento lasts for over 210 ms; *spectral appearance:* glide determines a large (or even the largest) part of the note; acceleration very likely
- **moderate** (code "m"): portamento's duration range is between 120 and 210 ms; *spectral appearance:* glide determines a smaller part of the note; acceleration rather likely
- **short** (code "s"): portamento's duration is shorter than 120 ms; *spectral appearance:* glide determines only a minuscule part of the note; acceleration rather unlikely

(5) Dynamics

Finally, the *Dynamics* subclass distinguishes between three modes of portamento 'volume' (that is, its amplitude level within the digital signal in the time domain) in relation to both its starting and target tones. In SV's spectrogram view, these level differences can be gathered from comparing the colour depths of the respective fundamentals and overtones. To execute more precise measurements, point to the related FFT windows and gather the bin dBFS values from the dialogue box.

- **louder** (code "+"): portamento comprises a level maximum which exceeds the levels of *both* the starting pitch offset (SPO) and the target pitch onset (TPO); *spectral appearance:* greater colour depths (usually: brighter colours) compared to SPO and TPO
- **stable** (code "="): portamento level ranges between the levels of SPO and TPO, respecting a tolerance of ±1 dBFS; *spectral appearance:* colour depths in between those of SPO and TPO
- **quieter** (code "-"): portamento's level maximum falls below the levels of *both* SPO and TPO; *spectral appearance:* smaller colour depths (usually: fainter colours) compared to SPO and TPO

83 Daniel Leech-Wilkinson, *The Changing Sound of Music: Approaches to Studying Recorded Musical Performance*, London 2009, http://www.charm.kcl.ac.uk/studies/chapters/intro.html, 21.02.2022, Ch. 8.2, Par. 71. Other sources report of a slightly lower threshold of 20 ms; see t'Hart / Collier / Cohen, *A perceptual study of intonation* (note 75), pp. 30f.

2. Inflection Indices

Besides providing ample terminologies for qualitative description and analysis, classifications of this kind entail at least another two decisive advantages: firstly, their value for quantitative large-scale studies, e.g., by expressing the respective phenomena as combinations of subclass codes, which allows for statistical evaluation. Secondly, each subclass may be arranged and weighted numerically according to its level within the respective main class, so that types with low levels would receive low numbers and those with high levels would receive high numbers. The culmination of subclass numbers would then allow for an indication of overall articulation, vibrato, and portamento level. For the purpose of this study, this cumulative variable has been named *Heuristic Inflection Index* (HII), or simply *Index* (I), for each of these phenomena (I_{Art}, I_{Vibr}, I_{Port}).

"Inflection", in loose analogy to linguistics, is defined here as *degree of deviation from a noiseless, steady sound*, where "steady" means each form of discrete-time change such as (periodical) alterations in pitch, volume, or duration. For instance, a (noisy) fricative articulation impulse deviates more from a noiseless sound than an (almost noiseless) sonorous one; a vibrato of a wide range deviates more from a steady sound than a vibrato of a small range. Thus, "inflection" is bound to realisations of single notes in an acoustical sense. Understood this way, it provides no information whatsoever about perceived intensity (i.e., salience) in a psychoacoustical sense or the aesthetic intensity of a musical performance in general, which both strongly depend on performance contexts as well as the listening socialisations of the recipients.[84] Furthermore, the indices have been named "heuristic" since they rely on subclass selections out of a theoretically limitless number of factors involved – even though these selections are by no means arbitrary, as explicated above. Understood this way, *Inflection Indices* may provide a useful source for performance analyses in indicating the acoustical prominence of single phenomena within various means of expression.

The inflection values for each subclass can be gathered from the respective classifications (FIGURES 1.1, 2.1, and 3.1): Each type has been weighted by (1) its rank within the subclass and (2) the weight of the subclass as a whole, resulting in *Index* factors for each type (the small numbers

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84 Likewise, the indices do not represent what Kilian Sprau calls the aesthetic "prominence" of portamentos. Instead, they must themselves be subject of interpretation, supporting Sprau's presumption that "measurement data on individual parameters of sound events […] do not necessarily reflect the aesthetic relevance that these events have in the context of a musical performance" and his plea for extended close listening approaches; see Sprau, "Ästhetische Relevanz zwischen Hören und Messen" (note 76), pp. 251f., quote p. 252 (my translations).

given in squared brackets).[85] To determine the cumulative *Index*, the relevant factors are multiplied by each other.[86] Finally, to improve intelligibility and comparability among different indices, the resulting values are converted to a scale with a maximum of 100 and rounded to whole numbers.[87] This means that each *Index* has a defined maximum of 100 (comparable to a percent scale).[88]

FIGURE 4 shows an exemplary comparison of three articulation *Indices* as 'volume' visualisations, which may correspond to (1) a *legato* stroke (I_{Art} = 11), (2) a *sautillé* stroke (I_{Art} = 20), and, by sharp contrast, (3) a stroke of maximum possible inflection (I_{Art} = 100) – the latter mirroring a common exertion of a (thrown) *sforzatissimo* impulse, followed by a fast *crescendo* and a sudden break-off. The coordinate axes are scale representations of the articulation subclasses *Impulse*, *Volume Development*, and *Duration*, which settle the respective cuboids' edges. The resulting 'volumes' represent the overall inflection degrees for each of the three strokes.[89]

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85 The subclass weightings have been determined based on two non-representative small-scale studies among music students at the University of Music and Performing Arts, Stuttgart (Germany), publication forthcoming.

86 The decision in favour of multiplicative instead of additive culmination has been made based on three assumptions: (1) that multiplication allows for more effective weighting (the impact of each value on the result increases), (2) to allow for diminishing factors (<1) such as in the vibrato subclasses of *Duration* and *Development,* and (3) to allow for subclasses or types that are considered neutral (factor: 1), such as the portamento subclass *Direction*.

87 See the "scaling factors" given in the lower right corner of each classification. For instance, to calculate the *Index* of a fast, medium-wide section vibrato without further range development, multiply the factors 0.6 (*Duration: section vibrato*), 3 (*Rate: fast*), 2 (*Range: medium*), and 1 (*Development: stable*) by each other, then multiply by vibrato classification's scaling factor (11.1): the resulting *Vibrato Index* amounts to 40. See FIGURE 4.1 for additional examples.

88 I would like to thank Tilo Hähnel for a discussion on the topic of indexing and some important advice. To avoid confusion, it should be emphasised that the indices presented here correspond to accumulations of the classification's respective subclass values. All of them are subjected to different ordinal scales, which is why calculations of statistical location measures (such as a median, mean, or standard deviation) across the subclasses are pointless. However, multiplicative culmination and comparison to *other* vibratos' culminations is among the permitted operations, even though the results do no longer allow for conclusions on the initial subclass values. In other words, two vibratos may exhibit the same cumulative *Inflection Index* (I_{Vibr}) of 48, but this tells nothing specific about their respective subclass qualities (since one may represent a *fast* [3], *medium wide* [×2], *increasing* [×0.9] *onset vibrato* [×0.8×11.1]; the other a *moderate* [2], *wide* [×3], *decreasing* [×0.9] *offset vibrato* [×0.8×11.1]).

89 Two special inflection factor cases should be explained: Firstly, the directions of portamentos might entail different aesthetical implications (such as the impression of 'sighting' as opposed to 'rapture'), but in the purely acoustical domain, there is

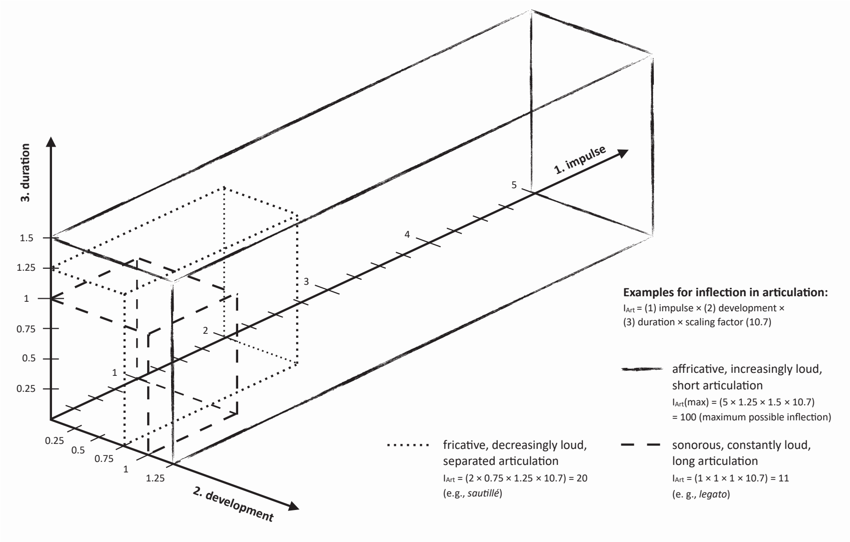
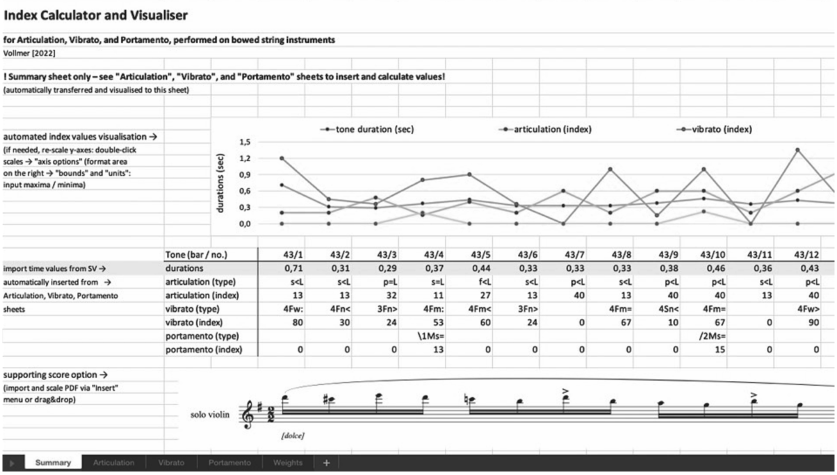


FIGURE 4: Articulation Index
as 'volume' visualisation in a three-dimensional coordinate system

In order to facilitate Inflection Index calculations, visualisations, and comparisons, an Excel template has been designed which can be retrieved from this volume's accompanying online repository at Zenodo. This workbook consists of five sheets: one for each articulation, vibrato, and portamento; one that automatically transfers all values into a summary and comparatively visualises them in a curve diagram, see FIGURE 5; and one that settles the weighting factors. Each sheet allows for a simple insertion of type indicator codes (see the yellow-highlighted cells), from which the indices are automatically calculated and visualised. Moreover, the "Vibrato" and "Portamento" sheets allow for easy calculations of *Rate*, *Range*, and *Duration:* the user only has to enter the respective frequency and time values obtained from the spectrograms, which are then converted to Hertz, cent, or time difference values, respectively. Additionally, a time value series may be added

no difference between the spectra of upward or downward portamentos. Therefore, the factors for *ascending* and *descending* are set uniformly to "1". Secondly, for some subclasses, the inflection factors are determined by their degree of convergence towards maximum inflection. In other words, a continuous vibrato without further development comprises factors of "1" for each *Duration* and *Development*, whereas a section vibrato that reaches its maximum for a momentary peak only (increasing and decreasing) entails diminishing factors of "0.6" and "0.8", respectively. The same applies to the subclasses *Volume Development* (articulation) as well as the *Link* and *Dynamics* (portamento).



Tone (bar / no.)	43/1	43/2	43/3	43/4	43/5	43/6	43/7	43/8	43/9	43/10	43/11	43/12
durations	0,71	0,31	0,29	0,37	0,44	0,33	0,33	0,33	0,38	0,46	0,36	0,43
articulation (type)	s<L	s<L	p=L	s=L	f<L	s<L	p<L	s<L	p<L	p<L	s<L	p<L
articulation (index)	13	13	32	11	27	13	40	13	40	40	13	40
vibrato (type)	4Fw:	4Fn<	3Fn>	4Fm:	4Fm<	3Fn>		4Fm=	4Sn<	4Fm=		4Fw>
vibrato (index)	80	30	24	53	60	24	0	67	10	67	0	90
portamento (type)				\1Ms=						/2Ms=		
portamento (index)	0	0	0	13	0	0	0	0	0	15	0	0

FIGURE 5: “Index Calculator” Excel template (summary sheet)

to the summary sheet to allow for comparisons with tone durations.[90] Spectrogram analysis and evaluation to determine the indicator codes still must be done externally (e.g., by using SV); however, the workbook design encourages the import of a supporting score which may facilitate the allocation of notes and tones.

3. Interpreting Expressive Means as Gestures

It is important to notice that articulation, vibrato, and portamento may each be largely independent means of expression, but they do not necessarily represent gestures per se: Occasional ‘outbursts’, such as a harsh accent within a rather quiet section, may be interpreted in this way – but this in return does not mean that *every single* incident (even of vibrato or portamento) should be understood as of gestural quality, for it might as well support a certain linearity.[91]

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90 The number of tones to be calculated may be extended at will by simply copying and pasting preceding columns; for the visualisation, the plot range then has to be expanded as well by right-clicking the chart → *Select Data…* → *Legend entries (series)* → click on a series’ name → *Y values:* → click on the little arrow icon → extend the data range in the sheet by expanding the frame with the mouse, press *Enter* → repeat for each series → *OK*.

91 For instance, singing and violin recordings from the beginning of the 20th century may suggest that portamento was applied out of habit rather than to mark expressive culmination points. Interestingly, over the course of the 20th century, a continuously applied vibrato seemed to replace portamento in this regard. See, e.g., Leech-Wilkinson, “Early recorded violin playing” (note 42), esp. pp. 21f.; Frithjof Vollmer, “‘Kreutzer’ und die Zwischenkriegszeit. Bruchlinien streicherspezifischer

The gestural 'potential' of expressive means largely depends on (but is not limited to) genre, style, and mood of the music, on the context of the performance such as room acoustics, the audience, or simply on the current state of the performer(s), and, not least, on the various recording and reproduction technologies in place.[92] Nonetheless, Expressive Gestures may be constituted by *breaking musical continuities at meso and micro level*, such as in creating culmination points within a phrase or in pointing out single, meaningful notes. Expressive means, such as articulation, vibrato, or portamento, may do so by their own or in combinations with each other.[93] However, it is the creation of brief 'spotlights' that seems crucial here, for the more a moment of elaboration interrupts an expected continuity, the more it may develop gestural emphasis. To conclude with an example, this approach will now be illustrated by a small case study.

4. Case Study: Beethoven's Op. 61 in Three Recordings (1934, 1944, 1953)

For a brief illustration of the classifications' potential for performance research purposes, Ludwig van Beethoven's Violin Concerto in D Major Op. 61 constitutes a convenient starting point: not only did it play an eminent role in both the composition and performance histories of violin concertos over the course of the 19th and 20th centuries, but also its *sounding* history – at least in studios and radio broadcasts – is well documented in numerous recordings from 1912 onwards.[94] Here, three of them are of particular interest: Bronisław Huberman's (1882–1947) Vienna studio recording from 1934,[95] Erich Röhn's (1910–1985) broadcast version from 1944 –

Vortragsästhetik im Spiegel früher Tondokumente zu Beethovens Violinsonate A-Dur op. 47, 1. Satz (1934–1936)", in: [Proceedings of the international *Beethoven-Perspektiven* conference, Bonn 2020, forthcoming].

92 For instance, an accent recorded by a microphone positioned very close to the musician might be reproduced disproportionately high compared to a microphone that is far away. The same holds true for various reproduction systems such as a HiFi system versus a car radio. This again leads to the conclusion that recordings in general represent merely a blurred picture of a performance (see the contribution of Claus-Peter Gallenmiller and Christian Zwarg to this volume).

93 Apart from these three, micro-timing, dynamics, and intonation (to name but a few) may also be considered as of gestural quality.

94 See, e.g., Robin Stowell, *Beethoven. Violin Concerto* (Cambridge Music Handbooks), Cambridge 1998; Mark Katz, "Beethoven in the Age of Mechanical Reproduction: The Violin Concerto on Record", in: *Beethoven Forum* 10/1 (2003), pp. 38–54. Back then, Katz listed Joan Manén's 1916 recording as the earliest (indicated as of 1922); meanwhile, Jan Rudényi's 1912 recording with excerpts from the 2nd and 3rd movements came to be known.

95 Bronisław Huberman (vl.), George Szell (cond.), Vienna Philharmonic, recorded 18.–20.06.1934, published on shellac disc set Columbia LX 509/13, matr. no. WHAX 30-4, 31-4, 32–2, 33-2, 34–1, 35–2, 36-3, 37-3, 38-3. Digital transfer at

being part of the last documented concert with Wilhelm Furtwängler at the Alte Philharmonie Berlin, 20 days before its bombing –,[96] and Henryk Szeryng's (1918–1988) Paris production from 1953.[97]

From their recordings, only a tiny part of the "Larghetto" will be considered: bars 43 and 44, being part of the cadenza-like solo violin transition towards the movement's second theme (or, as described by Owen Jander, the interruption of the *Romanze*).[98] This section appears to be virtually predestined for enacting Expressive Gestures: as the orchestral accompaniment pauses, time seems to stand still, and the soloist must create the transition on her own, only building on broken chords in the tonic. It is the beginning of a "drift off into a private world of contemplation",[99] culminating in a meditative second theme. In other words: this section may be regarded as a 'composed stage' for individual expressivity, an invitation to fill the plain but extensive space by gestural elements.

FIGURES 6.1 and 6.2 show Huberman's, Röhn's, and Szeryng's realisations of bars 43 and 44[100] with regard to their use of expressive means: durations for each semiquaver are complemented by a series of type indicators and their corresponding *Inflection Indices* for articulation, vibrato, and portamento. They are visualised in comparative line plots (both the series and the plots have been generated with the "Index Calculator" Excel template plate introduced above). The score indicates a long, descending

A4=447 Hz by Deutsches Rundfunkarchiv (DRA) Frankfurt a. M., level normalised. An excerpt of 15 seconds can be heard in SOUND EXAMPLE B1. I would like to thank Andreas Rühl and his team at DRA for their great support.

96 Erich Röhn (vl.), Wilhelm Furtwängler (cond.), Berlin Philharmonic Orchestra, recorded 09.01.1944, Alte Philharmonie Berlin, later published on LP Melodiya M10 40929/30. Digital transfer at A4=442.6 Hz, provided by YouTube channel "1Furtwangler", https://www.youtube.com/watch?v=JdRrMXKRgNA, 31.01.2022, level normalised. An excerpt of 20 seconds can be heard in SOUND EX. B2.

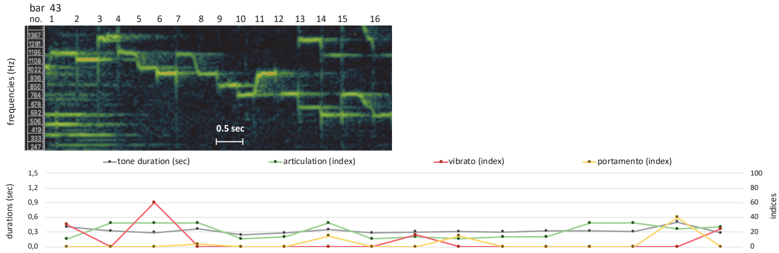
97 Henryk Szerying (vl.), Jacques Thibaud (cond.), Orchestre de la Société des Concerts du Conservatoire Paris, recorded 12.01.1953, Palais de Chaillot (Paris), published on LP Odeon ODX-109. Digital transfer at A4=443.4 Hz, prov. by YouTube channel "Deucalion Project", https://www.youtube.com/watch?v= 5Xtz3L3W6pc &t=54s, 31.01.2022, level normalised. Excerpted (15″) in SOUND EXAMPLE B3.

98 Owen Jander, "Romantic Form and Content in the Slow Movement of Beethoven's Violin Concerto", in: *The Musical Quarterly* 69/2 (1983), pp. 159–179, here p. 175.

99 Ibid.

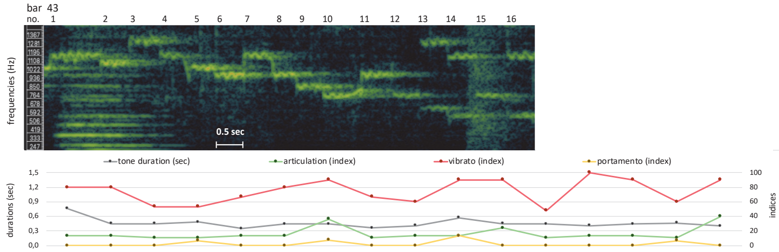
100 The notation has been taken directly from the very first collective edition by Breitkopf & Härtel, see Ludwig van Beethoven, *Concert für die Violine* (*Ludwig van Beethovens Werke* 4/29), Leipzig n. d. [1860–1890, plate no. B.29.], p. 39, which at least with regard to the violin sonatas has been considered as the standard and starting point for successive editions during the late 19th and the first half of the 20th century. See Clive Brown, "Einführung", in: *Beethoven. Sonaten für Klavier und Violine. Urtext*, vol. 1, ed. by ibid., Kassel etc. 2020, pp. XXXVII–XLVI, esp. p. XLIV.

Huberman 1934



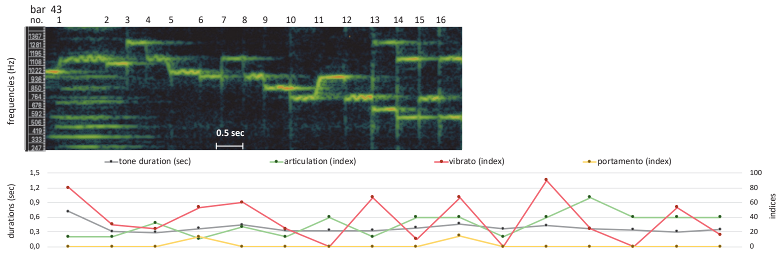
tone no.	43/1	43/2	43/3	43/4	43/5	43/6	43/7	43/8	43/9	43/10	43/11	43/12	43/13	43/14	43/15	43/16
duration 16ths (sec)	0.40	0.32	0.29	0.36	0.24	0.28	0.35	0.28	0.30	0.31	0.30	0.32	0.32	0.31	0.50	0.28
articulation (type)	s=L	p=L	p=L	p=L	s=L	s<L	p=L	s=L	s<L	s=L	s<L	s<L	p=L	p=L	p>L	f<L
articulation (index)	11	32	32	32	11	13	32	11	13	11	13	13	32	32	24	27
vibrato (type)	4Fn>		4Fm>						3Mn>							3Fn>
vibrato (index)	30		60						16							24
portamento (type)				\2Ss-			\2Ms=			/2Ms=					/1Ml=	
portamento (index)				4			15			15					40	

Röhn 1944



tone no.	43/1	43/2	43/3	43/4	43/5	43/6	43/7	43/8	43/9	43/10	43/11	43/12	43/13	43/14	43/15	43/16
duration 16ths (sec)	0.76	0.45	0.45	0.48	0.35	0.44	0.44	0.36	0.41	0.57	0.45	0.44	0.41	0.44	0.46	0.40
articulation (type)	s<L	s<L	s=L	s=L	s<L	s<L	p:L	s=L	s<L	s<L	p>L	s=L	s<L	s<L	s=L	p<L
articulation (index)	13	13	11	11	13	13	36	11	13	13	24	11	13	13	11	40
vibrato (type)	4Fw:	4Fw:	4Mw:	4Fm:	4Fm=	4Fw:	4Fw<	4Fm=	4Fm>	4Fw>	4Fw>	3Fm<	4Fw=	4Fw>	4Fm<	4Fw<
vibrato (index)	80	80	53	53	67	80	90	67	60	90	90	48	100	90	60	90
portamento (type)				\1Ms-			\2Ms-			/1Sm=					\1Sm-	
portamento (index)				7			7			13					7	

Szeryng 1953



tone no.	43/1	43/2	43/3	43/4	43/5	43/6	43/7	43/8	43/9	43/10	43/11	43/12	43/13	43/14	43/15	43/16
duration 16ths (sec)	0.71	0.31	0.29	0.37	0.44	0.33	0.33	0.33	0.38	0.46	0.36	0.43	0.37	0.34	0.30	0.35
articulation (type)	s<L	s<L	p=L	s=L	f<L	s<L	p<L	s<L	p<L	p<L	s<L	p<L	a<L	p<L	p<L	p<L
articulation (index)	13	13	32	11	27	13	40	13	40	40	13	40	67	40	40	40
vibrato (type)	4Fw:	4Fn<	3Fn>	4Fm:	4Fm<	3Fn>		4Fm=	4Sn<	4Fm=		4Fw>	3Fn>		4Fm:	3Mn<
vibrato (index)	80	30	24	53	60	24	0	67	10	67	0	90	24	0	53	16
portamento (type)				\1Ms-						/2Ms=						
portamento (index)				13						15						

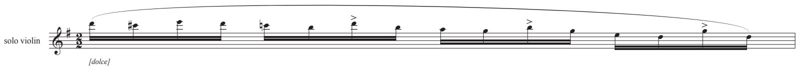
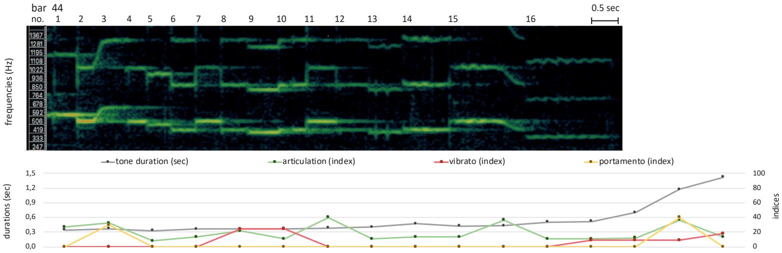


FIGURE 6.1: Ludwig van Beethoven, Op. 61, mvt. II, bar 43 in recordings of Huberman (1934), Röhn (1944), and Szeryng (1953)[101]

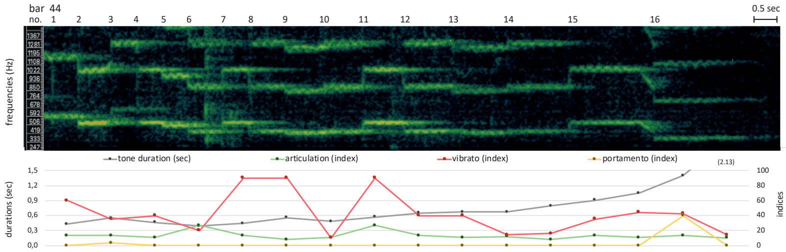
101 For figures in high definition see accompanying online repository.

Huberman 1934



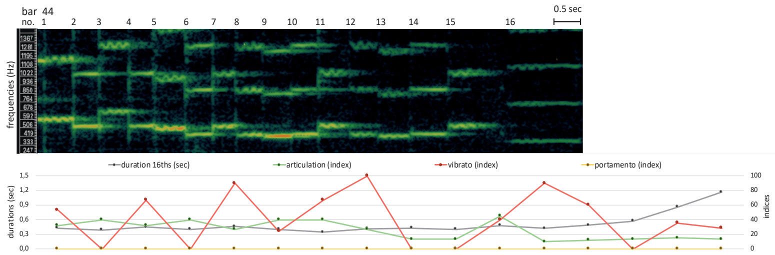
tone no.	44/1	44/2	44/3	44/4	44/5	44/6	44/7	44/8	44/9	44/10	44/11	44/12	44/13	44/14	44/15	44/16
duration 16ths (sec)	0.34	0.37	0.33	0.36	0.36	0.37	0.38	0.40	0.47	0.42	0.43	0.50	0.52	0.70	1.17	1.42
articulation (type)	f<L	p=L	s>L	s<L	f=L	s=L	p<L	s=L	s<L	s<L	p:L	s=L	s=L	s:L	p:L	s=E
articulation (index)	27	32	8	13	21	11	40	11	13	13	36	11	11	12	36	13
vibrato (type)					3Fn>	3Fn>							4Sn:	4Sn:	4Sn:	4Sm:
vibrato (index)					24	24							9	9	9	18
portamento (type)		/2Mm=													\1Ml=	
portamento (index)		30													40	

Röhn 1944



tone no.	44/1	44/2	44/3	44/4	44/5	44/6	44/7	44/8	44/9	44/10	44/11	44/12	44/13	44/14	44/15	44/16
duration 16ths (sec)	0.43	0.55	0.46	0.39	0.44	0.56	0.48	0.57	0.65	0.67	0.67	0.79	0.91	1.05	1.40	2.13
articulation (type)	s<L	s<L	s=L	f<L	s<L	s>L	s=L	f<L	s<L	s=L	s:L	s>L	s<L	s=L	s<L	s>E
articulation (index)	13	13	11	27	13	8	11	27	13	11	12	8	13	11	13	10
vibrato (type)	4Mw>	4Mm:	4Mm>	4Mn>	4Fw>	4Fw>	4Sn>	4Fw>	4Mm>	4Mm>	3Mn:	3Mn>	4Mm:	4Mm=	3Fm:	3Sm:
vibrato (index)	60	36	40	20	90	90	10	90	40	40	14	16	36	44	43	14
portamento (type)		/1Ss-													\1Ml=	
portamento (index)		3													40	

Szeryng 1953



tone no.	44/1	44/2	44/3	44/4	44/5	44/6	44/7	44/8	44/9	44/10	44/11	44/12	44/13	44/14	44/15	44/16
duration 16ths (sec)	0.43	0.39	0.45	0.40	0.46	0.40	0.34	0.42	0.43	0.40	0.48	0.42	0.48	0.57	0.86	1.16
articulation (type)	p=L	p<L	p=L	p<L	f<L	p<L	p<L	f<L	s<L	s<L	p:E	s>E	s:L	s<L	s:E	s<L
articulation (index)	32	40	32	40	27	40	40	27	13	13	45	10	12	13	15	13
vibrato (type)	4Fm:		4Fm=		4Fw>	3Fn>	4Fm=	4Fw=			4Mm>	4Fw>	4Fm>		4Mm:	3Mm:
vibrato (index)	53	0	67	0	90	24	67	100	0	0	40	90	60	0	36	28
portamento (type)																
portamento (index)																

FIGURE 6.2: Ludwig van Beethoven, Op. 61, mvt. II, bar 44
in recordings of Huberman (1934), Röhn (1944), and Szeryng (1953)

melodic line over the range of almost two octaves, which embellishes the chord notes of the movement's tonic G, subdominant C (Sixte ajoutée), and dominant D^7 by numerous suspensions and figurations, thus creating the impression of a full cadence before the beginning of the second theme.

Huberman's pre-war interpretation (also listen to ⤓ SOUND EXAMPLE B1) presents itself as rather unpretentious: the melodic line is realised in almost even semiquavers except for the very end, which sees a little *rallentando,* emphasising both the conclusion of the cadence and the beginning of a new theme. His articulation appears marked but not obtrusive by promoting a number of plosive and fricative tone impulses that highlight the beginning of the phrase, the transition between bars, and some of the accents prescribed by the score, such as in 43/7 and 44/7 (= bar / note number). However, Huberman thoroughly sounds in a broad *legato*, supported by occasional but discreet dynamical developments. Apart from that, he seems to ignore a number of articulation signs given by the score, such as half the accents and almost all staccato indications of the last eight notes. Striking, though, is his use of vibrato and portamento: After giving the highest note at the beginning (43/3) some emphasis by a fast, continuous, though decreasingly wide vibrato, he then largely abstains from it for the most part of the phrase except for a few inconspicuous occurrences, particularly towards its end.

However, *because* he uses vibrato sparingly, these last incidents come out as overtly striking, pausing the linearity of his playing for a moment of contemplation – herein, a clear case of an Expressive Gesture may be recognised. By sharp contrast, Huberman's portamentos appear to be exuberant: as many as six occurrences are crowded together. Despite their constant presence, three of these portamentos develop gestural qualities because of their relatively high *Inflection Indices* and their correlation with timing: those at notes no. 43/15, 44/2, and 44/15 also cause short-term decelerations and mark the attendant interval leaps this way.

By contrast, Röhn's mid-war reading (⤓ SOUND EXAMPLE B2) seems almost bacchanalian: Not only does he take by far the most time for the whole phrase (19 seconds), he also combines an extensive use of vibrato with occasional 'outbursts' in articulation and portamento such as in 43/7, 43/10, 43/16, 44/8, and 44/15. This way, the semiquavers sound as groups of four with high points around their central interval leaps: Röhn starts the first four groups with fast vibratos, strongly developing in range, complemented by some plosive articulations and numerous (though mostly short and quiet) portamentos. The second bar initially appears slightly more contained in both vibrato rate and range, but it is followed by an intense reblossoming at the second group of four semiquavers. A large *rallentando*, combined with a restrained vibrato revival and a conspicuous portamento at the very last interval leap, marks the end of the phrase. Röhn, as is apparent here, uses every expressive means available to present this transition as a weighty, almost pathetic, soloistic caesura before entering the contemplative mood of the second theme. Because of the almost constantly high inflection qualities, it would be difficult to interpret single incidents as of (insulated) gestural quality; rather, the whole phrase may be regarded as *one* comprehensive Expressive Gesture, with a fulminant beginning and intense aftermaths at the end of the phrase.

Ultimately, Szeryng's post-war performance (⤓ SOUND EXAMPLE B3) may constitute an intermediate way: he chooses from a wide range of different means and inflections to point out both melodic and harmonic high points. The first two groups of four are slightly lingering on their initial notes, supported by fast vibratos and short but clearly discernible portamentos; each forming subversive impressions of 'pausing' gestures. During the development towards the B5 from 43/9 to 43/11, raised inflection indices in articulation, vibrato, and portamento along with a slight *rallentando* form yet another gestural moment, this time in favour of a strong emphasis on the major third. From 43/12 onwards, articulation plays a prominent role. A long series of mostly plosive[102] and dynamically increasing tones form the impression of an unrelenting push until the phrase culminates in markedly separated tones at the phrase's *rallentando* end (which also makes Szeryng the only one respecting Beethoven's *staccato* signs).[103] Portamento, by contrast, is used rather inconspicuously in the first bar to underline the development of the leading note C♯6 in 43/2 towards a C6 as suspension in the G major chord in 43/5, and to emphasise the B5 in 43/11 (both portamentos are also performed by Huberman and Röhn – there might be a performance tradition here). However, it is completely absent in the second bar, giving room for other means of expression. This ultimately directs the attention to Szeryng's way of employing vibrato: after a homogenous opening, he alternatingly gives the vibratos either very high or very low inflections from 43/7 on (or none at all, respectively – indicated by the index graph's 'zigzag'), which results in a turbulent fluctuation of onbeat / offbeat vibratos. This way, he creates the impression of an agitated centrepiece until the phrase disperses in a mitigated ending. Overall, Szeryng's approach represents a quite balanced reading: far off Röhn's excessive qualities but also a strong contrast to Huberman's nonchalance, he shapes a transition that fluctuates between strong presence and introspection by making use of all expressive means equally. This way, Szeryng creates a both transparent and richly coloured interpretation of these two bars.

102 Unlike Szeryng's, the plosives of Huberman and Röhn are mainly caused by their percussive left hand technique ("Abklopfen").

103 These performance instructions are evident both in the preserved manuscript (see A-Wn: Mus. Hs. 17538, p. [13]) and in Breitkopf & Härtel's edition (note 100).

5. Prospects for Software-Based Performance Analyses

The analysis of expressive means may be of growing interest for performance research, as it promises revelatory insights that go far beyond the still predominant approaches to measure tempo and timing alone. The use of spectrograms for this purpose bears enormous potential to complement the findings from close listening and other proven methods. However, when it comes to *visualisations* of sounds, systematisations of what is seen in spectrograms become necessary to interpret them appropriately.

The classification approaches and their attendant *Inflection Indices* introduced here may be one way to make these visualisations viable. However, it must be mentioned that the resulting data has to be understood as subject to interpretation itself: a high index number, for instance, not always leads to higher aesthetic intensity or 'prominence'. Moreover, the 'objectivity' of a data series generated this way always depends on the research question as well as the qualities and contexts of the investigated sources.[104] Regarding the classification's subclasses, an investigation of statistical relevance in large samples has been omitted at this point; also, possible interdependencies have not been further questioned. Furthermore, the subclasses had to be selected from a wide variety of potential aspects – since other factors not considered here may play a prominent role, they should be applied with caution.

Bearing this in mind, the classifications and their indices may provide a basis for large-scale measurements, statistical evaluations, new visualisation methods, and future automated detection approaches (such as still to be developed SV plugins). This way, they complement the methodical toolbox towards a better understanding of expressive means and the complex phenomena of Expressive Gestures in music. The classifications and indices, then, may help with developing a highly promising field for software-based performance research purposes.

104 Also see Hähnel, "Automatische Vibratoanalyse" (note 3) and Sprau, "Ästhetische Relevanz zwischen Hören und Messen" (note 76).

APPENDIX 1

Index of files supplementing this article on Zenodo (cf. note 8)

File / Folder Name	Content(s)	Origin / Rights
1) Index Calculator (Art_Vibr_Port)	"Index Calculator" Excel template	Frithjof Vollmer (Creative Commons 4.0)
2) Figures	all figures in high resolution	Frithjof Vollmer
3) Sound Examples	SEs supplementing the case study and the classification examples	various (see APPENDIX 2)

APPENDIX 2

Index of historical sound examples in folder "3) Sound Examples" supplementing the classifications (see FIGURES 1.2, 2.2, and 3.2, respectively) and the case study (FIGURES 5.1 and 5.2); all files in 44.1 kHz, 16 Bit, mono, level normalised, FLAC format

File Code	Content	Origin	Digital Transfer
Case study: Beethoven Violin Concerto recordings, 1934–1953			
B1	Bronisław Huberman ([Vienna] 1934)	see note 95	
B2	Erich Röhn (Berlin 1944)	see note 96	
B3	Henryk Szeryng (Paris 1953)	see note 97	
Classifications: sound examples all examples given in: 1. full, 2. half, and 3. one-tenth playback speed (100 / 50 / 10 %) 1) Articulation: sound examples 1.1) Impulses			
vc	various phone examples ('affricative', plosive, fricative, sonorous voice consonants)	Frithjof Vollmer (recorded January 22th, 2022)	
a1	'affricative': 1. voice: [kʀɑ] 2. violin: Szigeti 1949, BWV 1006 ("Preludio", beginning, note no. 12) – 3. tone selection, full playback speed (100%) – 4. half playback speed (50%) – 5. one-tenth playback speed (10%)	1. voice: Vollmer (see above) 2. violin: József Szigeti (1892–1973), publ. on LP Vanguard BG 629, rec. February 13th, 1949 (New York)	1. ibid. 2. CD transfer: Music & Arts 774 (1993), excerpt (4″, minor revisions): Vollmer (2022)
a2	plosive: 1. voice: [tɑ] – 2.–5. violin: Szigeti 1949 (see above), notes nos. 1–3	ibid.	ibid.
a3	fricative / vibrant: 1. voice: [χʀ], [χ], and [ʀ] – 2.–5. violin: Szigeti 1949 (see above), note no. 32	ibid.	ibid.

File Code	Content	Origin	Digital Transfer
a4	sonorous: 1. voice: [ɑ] – 2.–5. violin: Szigeti 1949 (see above), note no. 6	ibid.	ibid.
1.2) Volume developments			
a5	increasing: Szeryng 1953, Beethoven Op. 61, 2nd mov. (bar 43, note no. 9)	see note 97	see note 97
a6	in- and decreasing: Heifetz 1935, BWV 1001, "Adagio", bar 4, note no. 14	Jascha Heifetz (1901–1987), shellac set HMV 1449, rec. December 11th, 1935 (London)	CD transfer: EMI Classics 7 64494 2 (1992), excerpt (7″, minor rev.): Vollmer (2022)
a7	constant: ibid., bar 12, note nos. 13–14	ibid.	ibid.
a8	decreasing: ibid., first chord	ibid.	ibid.
1.3) Durations			
a9	secco: Soldat-Röger 1920s, BWV 1006, "Preludio", bar 20	Marie Soldat-Röger (1863–1955), shellac matr. A 3005 (Lindström / Odeon), rec. 1920s [c. 1926] (Vienna)	CD transfer: Raymond Glaspole (1990),[105] excerpt (6″, minor rev.): Vollmer (2022)
a10	elastico: Szigeti 1949, BWV 1006, "Preludio", bar 1, note nos. 4–6	see above (a1)	see above (a1)
a11	lungo: ibid., bars 7–8	see above (a1)	see above (a1)
2) Vibrato: sound examples 2.1) Durations			
v1	continuous: Szeryng 1953, Beethoven Op. 61, 2nd mov., bar 46, note no. 6	see note 97	see note 97, excerpt (17″, minor rev.): Vollmer (2022)
v2	onset: ibid., bar 51, note n. 11	ibid.	ibid. – 10″ excerpt
v3	offset: ibid., bar 56, note no. 1	ibid.	ibid. – 5″ excerpt
v4	section: ibid., bar 45, note n. 1	ibid.	ibid. – 9″ excerpt
2.2) Rates and Ranges			
v5	fast and wide: Röhn 1944, Beethoven Op. 61, 2nd mov., bar 54, note no. 8	see note 96	see note 96 – exc. (13″, minor rev.): Vollmer (2022)
v6	moderate and medium wide: Szeryng 1953 (see above, v1), bar 51, note no. 1	see note 97	see note 97 – exc. (11″, minor rev.): Vollmer (2022)
v7	slow and narrow: Huberman 1934, Beethoven Op. 61, 2nd mov., bar 45, note nos. 1–2	see note 95	see note 95 – exc. (12″, minor rev.): Vollmer (2022)
2.3) Developments			
v8	stable: ibid., bar 47, ns. 2–3	ibid.	ibid. – 15″ excerpt
v9	increasing: ibid., bar 49, n. 2	ibid.	ibid. – 15″ excerpt
v10	decreasing: ibid., bar 54, note nos. 2–5	ibid.	ibid. – 8″ excerpt

105 I would like to thank Johannes Gebauer for kind support regarding this transfer.

File Code	Content	Origin	Digital Transfer
v11	in- and decreasing: ibid., bar 56, note no. 1	ibid.	ibid. – 8″ excerpt
3) Portamento: sound examples (mixed subclasses)			
p1	ascending, target, stable: Kreisler 1936, Beethoven Op. 47, 1st mov., bars 101–102	Fritz Kreisler (1875–1962), shellac set HMV DB3071/4, rec. June 17th–19th, 1936 (London)	CD transfer: Naxos 8.110969-71 (Ward Marston, 2003), excerpt (12″, minor rev.): Vollmer (2022)
p2	ascending, interconnecting, medium: Zimmermann 1926, Beethoven Op. 61, 2nd mov., bar 45, note nos. 1–2	Louis Zimmermann (1873–1954), shellac set Columbia 22/3 (5801/2), rec. Jan. 1926 (London)	Chris Zwarg (2021), excerpt (14″, minor revisions): Vollmer (2022)
p3	descending, starting: Zimmermann 1926 (ibid.), bar 44, notes 15–16	ibid.	ibid. – 7″ excerpt
p4	large: Kreisler 1936 (see above, p1), bars 109–110	see above (p1)	see above (p1) – 9″ excerpt
p5	small, louder: Kulenkampff 1935, Beethoven Op. 47, 1st mov., bars 99–100	Georg Kulenkampff (1898–1948), shellac set Polydor 35017/20, rec. May 27th and June 3rd, 1935 (Berlin)	Vollmer (2022)
p6	long: Zimmermann 1926 (see above, p2), bar 44, note nos. 2–3	see above (p2)	see above (p2) – 8″ excerpt
p7	moderate, quieter: Kreisler 1936 (see p1), bars 98–99	see above (p1)	see above (p1) – 6″ excerpt
p8	short: Szeryng 1953 (see above, B3), bar 43, note nos. 10–11	see above (B3)	see above (B3) – 6″ excerpt

Musik – Kultur – Geschichte

Im Auftrag des Instituts für Historische Musikwissenschaft
der Hochschule für Musik und Tanz Köln

Herausgegeben von
Arnold Jacobshagen, Sabine Meine und Michael Rappe

Band 15 – 2023

Softwaregestützte Interpretationsforschung

Grundsätze, Desiderate und Grenzen

Herausgegeben von
Julian Caskel
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