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»On the Quantification of the Diva. Vibrato, Ornamentation, Glissando, Tempo and Register in Acoustical Recordings between 1900 and 1930«,

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On the Quantification of the Diva

Vibrato, Ornamentation, Glissando, Tempo, and Register in Acoustic Recordings between 1900 and 1930

Tilo Hähnel

This study provides an analysis of some interpretation features in three specific arias as they are provided by recordings made between 1900 and 1930. My main interest was to focus on personal vocal styles as well as on developments of certain aspects of singing over the years. In my study, I used a mixture of quantification and computer-aided close-listening examination, which allowed for further frequency analyses (referring to the frequency of occurrence of certain phenomena, not to be confused with the frequency of a tone or one of its partials), and qualitative analyses. The statistics are used as information which can help create a theory. In other words, the approach is rather exploratory.

I had 16 recordings of the first part of »Una voce poco fa« (Gioachino Rossini, *Il barbiere di Siviglia*), another 10 of the second part, as well as 8 recordings of »Isoldes Liebestod« (Richard Wagner, *Tristan und Isolde*) (see Table 1). The analyses are divided into global and detail analyses, the global analyses including vibrato and tempo, the detail analyses comprising microtiming, ornamentation, and comments. As Table 1 shows, global analyses were based on all 34 recordings, and the detail analyses were based on 16 recordings of the first part of »Una voce poco fa«.

The procedure was the following: After blinding the filenames to hide the singer and year, the Software Sonic Visualiser was used for the quantification of several features in each recording that are related to the interpretation. That mainly required the setting of time markers and labels as well as the manual preprocessing of pitch curves.[1] The data were processed with the software environment R, because it is often used today for statistical analyses.

Aria	n	Global Analysis		Detail Analysis		
		Vibrato	Tempo	Mic. Tim.	Orn.	Com.
»Una voce poco fa«, part I	16	X	X	X	X	X
»Una voce poco fa«, part II	10	X	X			
»Isoldes Liebestod«	8	X	X			
Total	34	34			16	

Table 1: Material used for the present investigation; n: amount of recordings used; Mic. Tim.: microtiming analysis; Orn.: ornamentation analysis; Com.: comments.

[1] I thank Gregor Schmitz, who spent hours setting time markers on each measure and cleaning up pitch curves.

1 Global Analysis

1.1 Tempo

First, my assistant and I marked each single measure with a time-marker. It was then possible to compute the duration of each measure from these markers. These measure durations can be visualised as a curve, similar to the one shown in Figure 1 (left). To make curves of different arias comparable with each other, each individual curve was correlated with the average curve of the respective aria. A high correlation coefficient means a close distance between the respective curve and the average curve, and vice versa. When sorting the interpretations of one aria with respect to the correlation, very average-like samples can be found at the top end of the list, and very non-average like curves at the bottom. The top quarter of the list, hence, the quarter which correlates most with the average tempo curve of the aria, was marked with the label »Mean«; the bottom quarter was labelled »Deviant« accordingly. Table 3 provides the correlation and labels.

Since the year of the recording was known in most cases, it was possible to compare the labels with the years. Figure 1 (right) shows that not only the median differs between the groups, but the very distribution is also different. In the »Mean« group in the middle, apart from one outlier in 1914, there is no recording before 1925.
It seems as if deviant timing curves are found in early recordings, whereas later recordings show a mean timing. Unfortunately, the difference here is not statistically

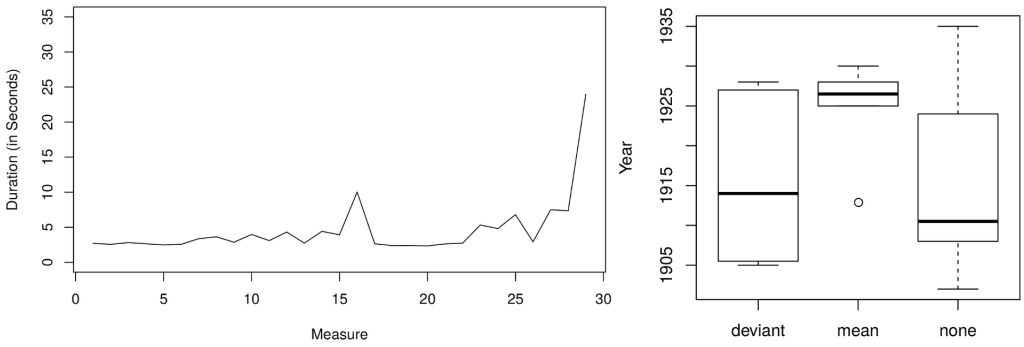


Figure 1: Left: Average curve of 16 recordings of »Una voce poco fa«. The horizontal axis shows the number of a particular measure, and the vertical position indicates its duration. The higher the curve, the longer the measure lasts. Right: Comparison of the three groups »Mean«, »Deviant« and »Neutral« with respect to tempo characteristics. The plots are so called boxplots. The bold line in the box represents the median, which is the point dividing the lower half from the upper half of a distribution. E.g. in the »Deviant« group, half of the recordings are from 1914 and earlier, the other half is later, respectively. The box frame covers the range of the central 50% around the median, which are between 1906 and 1926. The vertical lines outside the box are called whiskers. They show the complete range from the latest to the earliest recording. Only single outliers are not considered and marked separately with a dot. The boxplots further allow to estimate roughly how much data are overlapping between the groups.

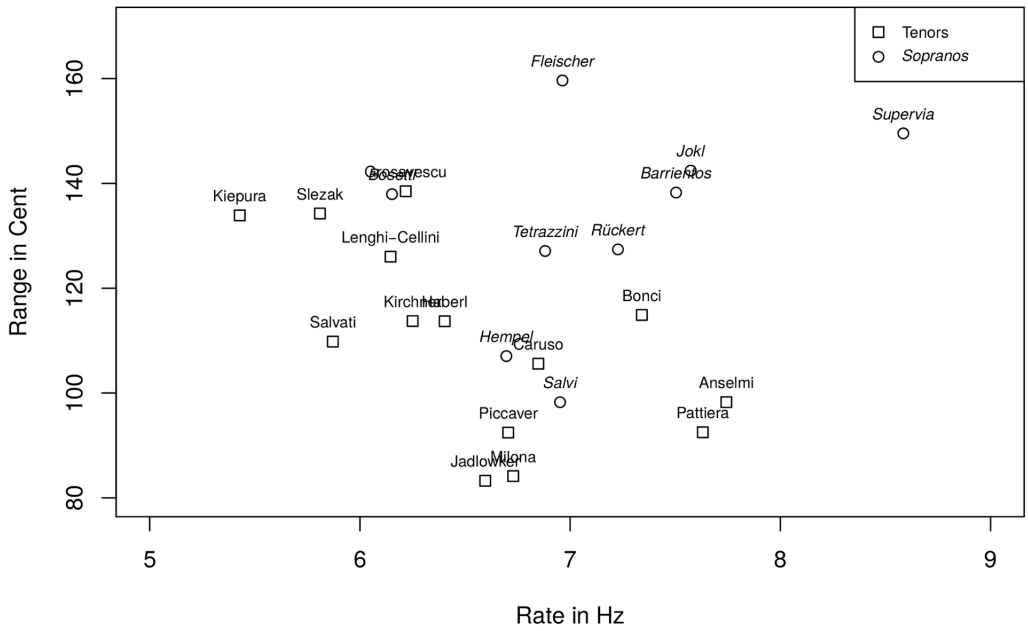


Figure 2: Recordings represented by the singer's mean vibrato within two dimensions of the pitch vibrato: vibrato rate, i.e. speed, given in vibrations per second, Hz; and vibrato range, i.e. the displacement of the pitch between the upper and lower reversal point, given in cent, with 100 cent = 1 semitone. The more the name is placed towards the right end, the faster the median vibrato rate of the particular artist is. The higher the artist is placed, the larger the median vibrato range is.

significant (a Wilcoxon rank-sum test with continuity correction showed $W = 17$, $p = 0.062$), but the direction is the same as I found in tenor arias.[2] Thus, this observation may nevertheless indicate that later recordings may have a tendency to become more equal in timing.

1.2 Vibrato

Figure 2 shows only those artists who are represented by at least two recordings. The plot includes the soprano singers from the present investigation and tenor singers from the aforementioned study. There seems to be a group hiding in the very centre, which includes very prominent artists: Luisa Tetrazzini, Frieda Hempel, and Enrico Caruso. They are not outstanding in their vibrato (otherwise they would be placed somewhere in the outer ranges). Of course, other prominent singers have a distinct vibrato, like Jan Kiepura and Leo Slezak, but it may not be a coincidence that some of the most prominent singers can be found in the middle. At least this concurs with the theory that beauty corresponds to the average.[3] The Figure also indicates that the sopranos have a slightly higher range and faster speed than the tenors. The difference

[2] This analysis has been presented at the Conference of the German Musicological Society / Gesellschaft für Musikforschung (GfM) in Osnabrück 2018.

in speed particularly shows a statistically large effect: A two sample *t*-test showed that the sopranos had a mean vibrato rate of 7.12 Hz and the tenors a mean rate of 6.58 Hz, a difference which is highly significant ($t_{(68)} = 2.95$, $p = 0.004$, $d = 0.73$ [0.47; 0.99])[4].

2 Detail Analysis

The detail analysis includes microtiming, ornamentation, and comments. The microtiming analysis further includes investigations of tone durations and tone proportions.

2.1 Microtiming

Tone Proportion

The prolongation of tone durations beyond their theoretical value has a strong influence on the perceived character of the music. Depending on the state of arousal expressed through the interpretation, musicians often change the dotting of their rhythms. This has been shown by Alf Gabrielsson, Patrik N. Juslin[5] and colleagues[6] in numerous experiments since the 1980s.[7] If an interpreter tries to convey an expression of excitement, be it very happy or aggressive, rhythmic contrasts are usually exaggerated, but if a tender or sad mood is expressed, these contrasts are often dimin-

[3] *Cf.* an overview: Anna Wolf *et al.*, »Tendency Towards the Average? The Aesthetic Evaluation of a Quantitatively Average Music Performance: A Successful Replication of Repp's (1997) Study«, in: *Music Perception* 36 (2018), pp. 98–108. In her article, Wolf refers to Bruno H. Repp, »The Aesthetic Quality of a Quantitatively Average Music Performance: Two Preliminary Experiments«, in: *Music Perception* 14 (1997), pp. 419–444, and also quotes the now ›classical‹ study from Judith H. Langlois and Lori A. Roggman, »Attractive Faces Are Only Average«, in: *Psychological Science* 1 (1990), pp. 115–121.

[4] The statistics include the empirical Cohen's *d* as well as its 95% confidence interval (CI), as strongly suggested in Friedrich Platz, Reinhard Kopiez and Marco Lehmann, »Statistische Poweranalyse als Weg zu einer ›kraftvolleren‹ Musikpsychologie im 21. Jahrhundert«, in: *Musikpsychologie* 22 (2012), pp. 165–179, here pp. 170–171.

[5] *Cf.* Alf Gabrielsson and Patrik N. Juslin, »Emotional Expression in Music Performance: Between the Performer's Intention and the Listener's Experience«, in: *Psychology of Music* 24 (1996), pp. 68–91; Alf Gabrielsson, »Studying Emotional Expression in Music Performance«, in: *Bulletin of the Council for Research in Music Education* 141 (1999), pp. 47–53.

[6] *Cf.* Anders Friberg, »Generative Rules for Music Performance: A Formal Description of a Rule System«, in: *Computer Music Journal* 15, No.2 (1991), pp. 56–71; Anders Friberg, »pDM: An Expressive Sequencer with Real-Time Control of the KTH Music-Performance Rules«, in: *Computer Music Journal* 30, No.1 (2006), pp. 37–48.

[7] *Cf.* Tilo Hähnel, *Baroque Performance. A Research Study on Characteristic Parameters of 18th Century Music*, Osnabrück 2013 (= Studies in Cognitive Musicology, vol. 2).

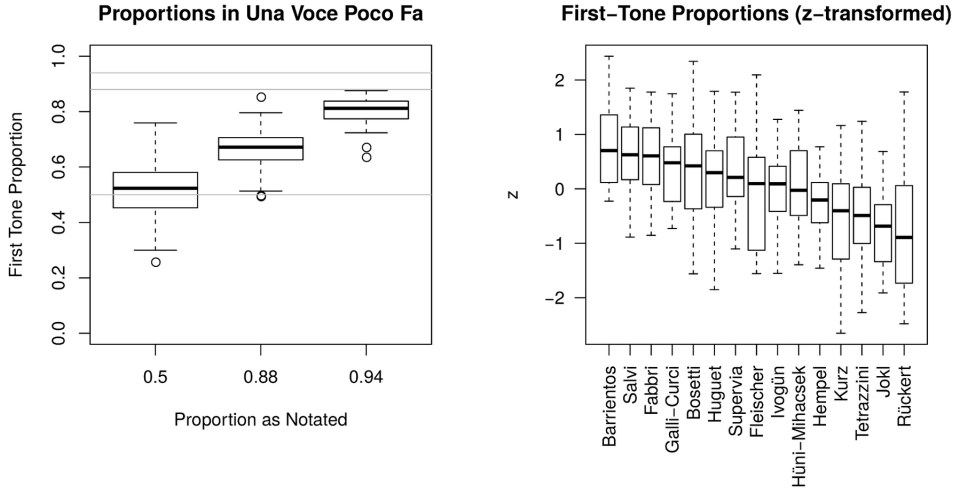


Figure 3: Tone proportions as shown in the recordings. Left: Proportion of the first tone according to its theoretical, i.e. notated proportion. There is a clear tendency for diminishing the contrast of tone durations. The boxplots are below the theoretical position indicated with gray lines. Right: z-transformed proportions for each singer. A z-value > 0 means a proportion larger than the average proportion; z = 1 equals a proportion larger than one standard deviation. Differences between performers are clear, because some are nearly completely above zero, and others below zero.

ished.[8] Therefore, the actual proportion of such a rhythm can function as a personal characteristic of a singer's general approach. That's why it is worth looking at some selected rhythms. The tone proportions of three different rhythms in the renditions of »Una voce poco fa« (see * in Figure 6)[9] were measured and the results compared to their theoretical proportion. In theory, these proportions should have been 50%, 88%, or 94%. Figure 3 shows that the proportions of the performed tones differed not only from the theoretical proportion, but also among the performers.

For a comparison of the performers, the groups had to be made comparable, *i.e.* independent from the different theoretical proportions and the position in the score. Therefore, a z-transformation was used, which shifted each distribution ›downwards‹ until it average became zero, and then stretched it until it variance became one. After a z-transformation, the information about the exact proportion sung by an artist gets lost, but it is still possible to tell if the artist's proportions are above the average or below, now irrespective of the theoretical proportion. Figure 3 (right) shows the z-transformed proportions of each performer. There are indeed differences, where the

[8] *Cf.* n. 5.

[9] Based on the score taken from Gioachino Rossini, *Il barbiere di Siviglia. [Almaviva o sia L'inutile precauzione]. Commedia in due atti. Libretto by/di Cesare Sterbini after/dalla commedia* [*by/*]*di Pierre-Augustin Caron de Beaumarchais*, ed. by Patricia B. Brauner, [vol. 1], Kassel etc. 2008 (= Works of / Opere di Gioachino Rossini, vol. 2), pp. 142–154.

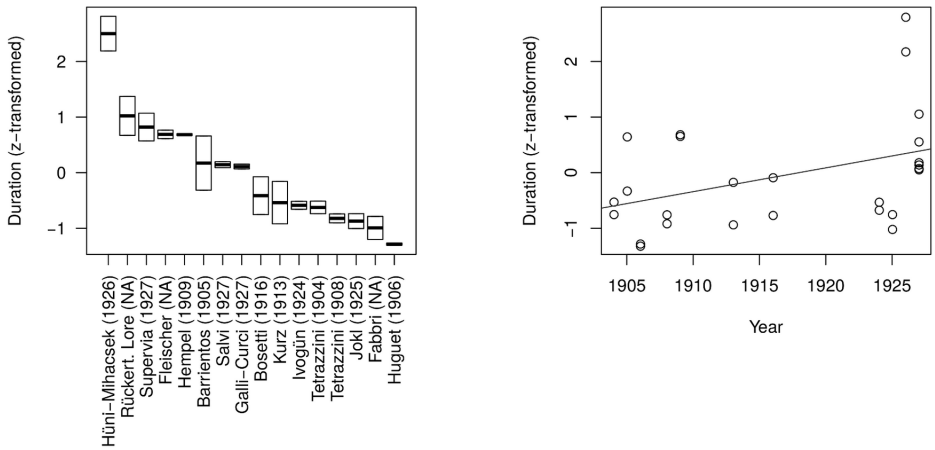


Figure 4: Tone duration as performed. z-values show relative differences between singers. Left: Comparison of the z-values between the singers. Right: Year of the record plotted against mean z-values, indicating an increase in tone duration for high-peaked notes.

German singers seem to be at the lower end, having a tendency to smooth out the differences, and the Italians, who seem to pronounce differences of tone duration more intensely. One exception is the Italian Tetrazzini, who is again among the other prominent German figures, Hempel, and Selma Kurz. However, prominent singers like Amelita Galli-Curci show that a smaller proportion is no indication for success.

Tone Duration

The analysis of the durations of tones focussed on tones which are often sung substantially longer than notated (mostly high-peak tones, see Δ in Figure 6). In her memoires, Hempel wrote that she prolonged high notes deliberately.[10] Figure 4 shows the singers' z-values for duration. Hempel clearly tends to sing these tones longer, whereas other prominent singers of the time, like Tetrazzini and Kurz, can be found at the lower part of the continuum. When comparing the year of the recording with the tone duration, there is an increase of tone duration over the years, which can be expressed by a correlation. Due to a non-normal distribution of the samples and the small amount of data, the Pearson correlation coefficient r could not be used. Instead, the more robust alternative of the Kendall rank correlation coefficient τ, was used ($\tau = 0.305$, $p = 0.036$).[11] However, Figure 4 (right) indicates that the positive correlation and the significant effect of year on the tone duration seems to be based on some extreme recordings after 1925. This is important, as in this year the electric recording technique was introduced. It seems that this new technology may have had a great impact on recording singing practice.

[10] Frieda Hempel, *Mein Leben dem Gesang. Erinnerungen*, Berlin 1955, p. 140.

[11] *Cf.* Peter Sedlmeier and Frank Renkewitz, *Forschungsmethoden und Statistik für Psychologen und Sozialwissenschaftler*, 3rd revised and expanded edition, Hallbergmoos 2018, pp. 239–242.

The results so far still provide no indication for the outstanding quality of artists like Luisa Tetrazzini. This will change in the following section dealing with ornamentation.

2.2 Ornamentation

In this paper, the ornamentation is used as an umbrella term, covering three different kinds of ornaments:

1. portamenti, which will be discussed in the following,
2. musical ornaments, like a trill, or a grace note,
3. non-verbal expressions, like audible and voiced breathing and sighing.

Portamenti

All portamenti were marked at the time of their start and end and labelled according to their characteristics and direction. When trying to measure the length of a portamento exactly, it becomes evident that there is no phenomenological distinction between a nearly step-like transition between two pitches and a glide. It was essential, however, to exclude small pitch transitions which are not perceived as a portamento. That distinction between a non-recognisable transition and an obvious portamento is not always clear. In fact, in most cases a distinction is quite a challenge. Nevertheless, a decision for or against a portamento should be based on some valid grounds. Therefore, a threshold of 250 ms was set as the minimum length of a glide to account for a portamento. This threshold is based on the hypothesis that the human ear needs a minimum of 250 ms (200–300 ms) to optimally analyse the pitch and loudness of a tone.[12] A threshold exceeding this time interval allows a listener to perceive a glide as a glide and to listen to its progression.

Table 4 shows the accumulated lengths of all glides for each singer. The total duration of gliding of Felicie Hüni-Mihacsek amounts to more than 20 s; the one of Tetrazzini is about 2 s, because she barely glides at all. In the following, only the singers with much gliding are considered further, by looking at how much gliding is sung with a vibrato. This choice is based on the observation that a vibrato on a long glide is a very obvious and intense effect. It is obvious, that despite Hüni-Mihacsek's intense use of the glide, she seems cautious adding a vibrato, contrary to Editha Fleischer or even Concita Supervia, who almost always uses the vibrato.

[12] *Cf.* Jobst P. Fricke and Christoph Louven, »Psychoakustische Grundlagen des Musikhörens«, in: *Musikpsychologie. Das neue Handbuch*, ed. by Herbert Bruhn, Reinhard Kopiez and Andreas C. Lehmann, Reinbek 2008 (Rowohlts Enzyklopädie, vol. 55661), pp. 413–436, here p. 434. Fricke and Louven refer to the benchmark of 250 ms by quoting Christoph Reuter, *Der Einschwingvorgang nichtperkussiver Musikinstrumente. Auswertung physikalischer und psychoakustischer Messungen*, Frankfurt am Main 1995 (= Europäische Hochschulschriften, series 36, vol. 148), p. 34.

When correlating the years with the number of portmenti that include a vibrato as well, it seems as if the number of vibrating portamenti increases with time (r = 0.59 [0.06; 0.86], $t_{(11)}$ = 2.42, p = 0.034)[13]. But this increase is again due to the very late recordings. There is no indication of an increase before 1925.

Ornaments

Ornaments were marked in the recordings according to a label catalogue which is shown in Table 5. When correlating the amount of ornaments with the year of recording, particularly the musical ornaments decreased with the years (r = −0.66 [−0.89; −0.18], $t_{(11)}$ = −2.95, p = 0.013). Here, we finally have Tetrazzini on top of the list, and even two times, 1904 and 1908. Of the musical ornaments, the coloratura is of particular interest: Tetrazzini uses the most coloraturas, followed by a decrease until 1925; then we have an increase again, or, to be more precise, an increase of variability in the use of coloraturas.

2.3 Comments

The comments were included directly into the visualisation in a text layer of the Sonic Visualiser. Afterwards, they were aligned with the measure-labels for an easier comparability between the interpreters.

The comments may be explained best by looking at three examples, Supervia, Hempel, and Tetrazzini, singing the following passage:

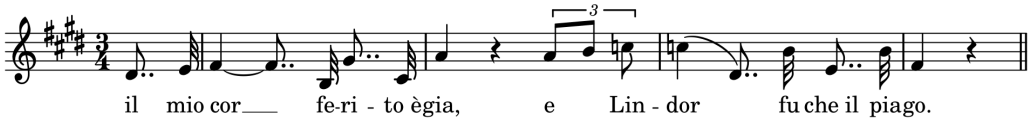


Figure 5 shows the Sonic Visualiser's spectrogram view, where the overtones are superimposed by a white curve, which is the estimation of the pitch that is sung.[14] Also superimposed are the annotation layer, the labels for microtiming, portamenti and ornaments. For instance, those labels beginning with a »t« are all mictrotiming labels, and those with »p« are all portamenti of different kinds, labelled according to the predefined catalogue (see Table 5). By using a clear code system, a computer

[13] The square brackets include the 95% CI for Pearson's *r*.

[14] The pitch was estimated by the Smoothed Pitch Track algorithm of the pYin plugin. *Cf.* Matthias Mauch *et al.*, »Computer-aided Melody Note Transcription Using the Tony Software: Accuracy and Efficiency«, in: *First International Conference on Technologies for Music Notation and Representation. TENOR 2015. 28–30 May, 2015. Université Paris-Sorbonne / Ircam. Paris*, ed. by Marc Battier *et al.*, Paris 2015, pp. 23–31; Matthias Mauch and Simon Dixon, »PYIN: A Fundamental Frequency Estimator Using Probabilistic Threshold Distributions«, in: *2014 IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, [ed. by the Institute of Electrical and Electronics Engineers (IEEE)], Piscataway 2014, pp. 659–663.

routine can analyse them easily. The comments are actually texts written directly into the spectrogram. The purpose of the comments was not predefined, but it turned out that they were useful for three reasons:

1. to clarify a decision regarding a marker,
2. to record spontaneous ideas and impressions and
3. to record anything that could not be covered by the label catalogue.

The qualitative analysis of the comments loosely follows the method of content analysis of written texts.[15] For instance, in the Supervia example I commented »croonerglissando«, because the shape of the glide is upwards and with the steeper part at the right. This shape can be found very often in 1920s and 1930s recordings of crooner-songs.[16] Its characteristic shape is somehow contrary to the usual shape of portamenti in the other soprano recordings. When singing a ›classic‹ portamento, the artist usually anticipates the new pitch and ends the portamento before the new tone. This way of portamento concurs with the theory of that time and with late 18th-century treatises on singing.[17] The Crooner's glide, however, starts not until the new note and therefore lags behind.

In the passage sung by Supervia there is also an ornament label **rb**, meaning *Register/Bruststimme* (*i.e.* chest voice).

In contrast to Supervia, Hempel uses more legato and more portamenti, but avoids applying a vibrato onto the portamento. There are two comments. The first one refers to the ornament, and the second refers to the register. Since the head voice was not labelled, for it is the standard setting for sopranos, the comment became necessary, because a change in register was expected here. The comment states that the voice sounded very light and soft, which is surprising, for most other singers made use of their chest voice, even stressing the contrast to the head voice by singing with a deep sounding and loud tone. The impression of the head voice may be influenced by a noise reduction, which had obviously been applied to this digital sound-file. Especially when used intensely, noise reduction reduces not only the noise but some over-

[15] *Cf.* Philipp Mayring, *Qualitative Inhaltsanalyse. Grundlagen und Techniken*, 11th updated and revised edition, Weinheim/Basel 2010 (= Beltz Pädagogik).

[16] *Cf.* Tilo Hähnel, »›The Cutest Flapper That You've Ever Seen‹. Über die Anfänge des Crooning«, in: *Stimme, Kultur, Identität. Vokaler Ausdruck in der populären Musik der USA, 1900–1960*, ed. by Martin Pfleiderer, Tilo Hähnel, Katrin Horn and Christian Bielefeldt, Bielefeld 2015 (= texte zur populären musik, vol. 8), pp. 129–150.

[17] *E.g.* Ferdinand Sieber, *Katechismus der Gesangskunst*, Leipzig 1862, p. 39; August Iffert, *Allgemeine Gesangschule*, vol. A: *Theoretischer Teil*, 4th edition, Leipzig 1906, p. 43; Eugen Fischer, *Neue Gesangsschule mit praktischen Beispielen auf dem Grammophon*, Leipzig 1910, p. 36, here referring to the statement of the mezzo-soprano singer Laura Higermann, and referring to himself, p. 104.

tones as well. However, the difference to a full grown chest voice can be heard clearly in the recording of Tetrazzini.

Tetrazzini's register break is very close to yodelling. There are many comments included in the Figure, the last one being a note that this singer may even remind one of Ella Fitzgerald for the following reason. In a previous work on the interpretation of the Jazz-standard ›Body and Soul‹,[18] it became evident that transcribing Ella Fitzgerald's singing is surprisingly easy, despite her ornaments. The easiness is due to her precise pitches and metrical alignment with the band. It seems even comparatively easy to decide whether she used ternary or binary quavers. Fitzgerald's articulation is very clear even in fast and complex passages. Compared to other Jazz singers, she usually starts singing without using ornaments at all. She strictly sticks to the notes and even avoids minor changes usually made by Jazz singers. In the process, however, she adds some variant here and there, gradually intensifying her ornamentation until her embellishments become intense.[19] This behaviour is indeed similar to the one which can be observed listening to Tetrazzini. Although Tetrazzini showed more ornaments in her recordings than any other singer of the sample analysed here, she sings very clearly and even neatly at the beginning. She even avoids the prolongation of high notes. She merely sings the notes, but as the aria progresses, she shows more and more of her art of coloratura.

3 Summary

In the recordings that have been analysed, there was a slight tendency to normalise the tempo characteristics between 1900 and 1930. Also, and maybe more importantly, an increase of portamento showed up. Musical ornaments, above all coloraturas, decreased until 1925. These observations may be a hint for a general change of interpretation, where musical embellishments were used less in favour of a more pronounced sound, which is, for instance, expressed in long glides. The musical ornament can be interpreted as a more intellectual feature of the interpretation, because a coloratura requires the transformation of expression into tones added to the score. A coloratura therefore needs to be understood by the listeners as well. In contrast to the coloratura, vocal sounds and non-musical ornamentations can be seen as direct and even physical representations of the singer's personality. I use the term personality here, because it was used increasingly in the field of classical music as well as popular music at that time. So the last question, which might evolve from that theory, is whether we are facing a popularisation of sound and a loss of musical codes, such as coloraturas.

[18] *Cf.* Tilo Hähnel, »›For You I Sigh, for You, Dear, Only‹. Torch Song im Jazz«, in: *Stimme, Kultur, Identität*, pp. 151–173, here pp. 166–168.
[19] *Ibid.*

		Tetrazzini	Kurz	Hempel	Supervia
Tempo					*deviant*
Vibrato	**Range**		**hi**		**hi**
Timing	**Duration Prolongation**	*short*	*short*	**long**	**long**
	Proportion	*lower*	*lower*		
Portamenti	**With Vibrato**		**mid hi**		**hi**
	Direction			*down*	
	Characteristic		**left-steep**	*right-steep*	*right-steep*
Other	**Musical Ornaments**	**many**		*few*	*few*
	Coloraturas	**many**			*few*
	Use of Chest Voice	**hi**	**mid hi**	*low*	**hi**

Table 2: Simplified summary of the personal characteristics of four singers based on the overall-results.

Table 2 gives a summarising overview of the four singers Tetrazzini, Hempel, Kurz, and Supervia. These four different personal styles are based on quantitative and qualitative observations and they emphasize the trends observed in the analyses. Therefore, these four recordings may work as prototypes for the aforementioned historical changes: Tetrazzini rarely uses long glides and she does not prolong notes generally, be it tone proportions or fermatas, but she uses musical ornaments like nobody else. Hempel sings long fermatas and often uses glides but avoids applying a vibrato on the glide. Kurz glides as well, but she uses more glissandi with a vibrato. Kurz' vibrato is generally of a larger range than the other two. Like Tetrazzini, Kurz also shows a distinct chest voice. If we understand the register contrast as a non-musical ornament, then this is the only non-musical ornament that was used in the early recordings. However, its usage does not vanish, but it is used with increasing variability among the performers. For instance, it is also used by Supervia, who may serve as the modern type in this comparison, showing less musical ornaments and less coloraturas, but making intense use of portamenti and prolonged tones and showing a larger vibrato range, too. The deviant tempo she shows is rather an exception here.

At the beginning of the whole project *Technologies of Singing – Investigations on the Dispositive Singing – Body – Media at the Dawn of Sound Recording*, one hypothesis was that singers may have started to use a permanent vibrato. When taken literally, this hypothesis cannot be confirmed. On the contrary, there was no recording without a permanent vibrato, with the exception of very few tones and glides. Therefore, a further increase in vibrato is hardly possible. However, the impression of an increasing vibrato has a point and probably it can be explained by three arguments: first, the portamento. When used with a vibrato, a portamento has a strong effect and the vibrato is very obvious. Second, the discourse. There is the possibility that despite the variability of singing, there are some recordings that are used as rep-

resentative recordings in a discourse. As ›discoursive events‹[20] these few recordings might dominate the impression, although they do not represent the variability that can be found among all recordings. And last but no least, it is possible that the vibrato changed in its characteristics, like its speed or range. Although there was no such change in this sample, it is possible that intense changes took place after 1925. The very few examples from the time after the invention of the electric recording technique already suggest that there may be a major change of singing styles.

As a last point there should be a warning not to over-interpret these results. Quantitative studies are very appealing, because numbers are concrete and seem to express hard facts. They have the aura of truths. However, this study was an exploratory study and therefore not hypothesis-driven. Thus, we cannot use the numbers to substantiate a theory we created with the help of these very numbers. That would indeed be circular reasoning. And, of course, we cannot infer the reason for the observed differences from the data. Still, the results are very helpful, if we connect them with the other findings made in our project *Technologies of Singing*.[21] Then they can contribute to a well documented theory and provide a quite sound argument.

[20] Referring to ›discoursive events‹, see Siegfried Jäger, *Kritische Diskursanalyse. Eine Einführung*, 6th completely revised edition, Münster 2012 (= Edition DISS, vol. 3), pp. 80–85.

[21] http://www.hfm-detmold.de/die-hochschule/forschung/aktuelle-projekte/technologien-des-singens-dfg/; http://gepris.dfg.de/gepris/projekt/289601849, both 27th August 2020.

Appendix

Aria	Name	Year	Vibrato Median Values		Tempo	
			Rate in Hz	Range in Ct	Corr.	Lab.
»Una voce poco fa« (I)	Tetrazzini, Luisa	1904	6.9	145	0.968	
	Barrientos, Marie	1905	7.3	135	0.976	
	Huguet, Josefina	1906	7.7	101	0.936	D
	Tetrazzini, Luisa	1908	6.8	109	0.977	
	Hempel, Frieda	1909	6.6	100	0.983	
	Kurz, Selma	1913	6.6	159	0.989	M
	Bosetti, Hermine	1916	6.1	125	0.823	D
	Ivogün, Maria	1924	6.8	123	0.973	
	Jokl, Fritzi	1925	7.6	137	0.985	M
	Hüni-Mihacsek, Felicie	1926	6.7	119	0.989	M
	Galli-Curci, Amelita	1927	6.4	114	0.944	D
	Salvi, Margherita	1927	6.9	93	0.989	M
	Supervia, Conchita	1927	8.6	155	0.955	
	Fabbri, Guerrina	> 1925	6.7	113	0.951	
	Fleischer, Editha	< 1925	6.9	137	0.934	D
	Rückert, Lore	< 1925	7.2	126	0.981	
»Una voce poco fa« (II)	Abendroth, Irene	1902	9.4	110	0.855	
	Barrientos, Marie	1905	7.7	141	0.829	D
	Wedekind, Erika	1905	7.3	128	0.720	D
	Hempel, Frieda	1910	6.8	114	0.898	
	Bosetti, Hermine	1916	6.2	151	0.901	
	Jokl, Fritzi	1925	7.6	148	0.959	M
	Salvi, Margherita	1927	7.0	104	0.925	M
	Supervia, Conchita	1927	8.6	144	0.854	D
	Fleischer, Editha	< 1925	7.0	182	0.958	M
	Rückert, Lore	< 1925	7.2	129	0.869	
»Isoldes Liebestod«	Nordica, Lillian	1910	6.4	88	0.860	
	Kurt, Melanie	1912	7.8	80	0.820	D
	Hafgren-Waag, Lilly	1913	7.0	120	0.928	
	Seinemeyer, Meta	1928	7.5	106	0.849	D
	Ohms, Elisabeth	1929	7.4	124	0.930	M
	Lehmann, Lotte	1930	7.1	127	0.929	M
	Flagstad, Kirsten	1935	6.3	101	NA	
	Destinnová, Ema	< 1915	6.4	118	0.913	

Table 3: Summary of the global analysis. Rows are sorted according to the aria and the year the record was first published. Columns four and five show the median vibrato range and rate for each vocal signal in the record. Columns six and seven summarise the tempo analysis. Corr.: correlation of the tempo curve (*i.e.* duration of the measures) and the mean tempo curve of all recordings from the respective aria. Lab.: labels indicating a »Deviant« tempo curve (D) and a »Mean« tempo curve (M).

Name	Year	Portamenti (≥ 250 ms)				Ornaments	
		all		+ Vibrato			
		n	dur	n	dur	Mus	Col
Tetrazzini, Luisa	1904	2	1.0	1	0.3	21	3
Barrientos, Marie	1905	3	1.1	3	1.1	16	7
Huguet, Josefina	1906	1	0.3	1	0.3	20	8
Tetrazzini, Luisa	1908	6	2.2	2	1.0	20	6
Hempel, Frieda	1909	11	5.6	4	2.7	13	6
Kurz, Selma	1913	21	11.3	3	4.2	16	5
Bosetti, Hermine	1916	13	5.1	2	0.8	12	2
Ivogün, Maria	1924	15	5.9	6	2.2	13	7
Jokl, Fritzi	1925	15	16.6	5	2.6	13	3
Hüni-Mihacsek, Felicie	1926	47	21.6	4	2.1	14	6
Galli-Curci, Amelita	1927	4	1.2	1	0.3	13	5
Salvi, Margherita	1927	8	3.1	6	2.4	17	5
Supervia, Conchita	1927	12	3.8	11	3.5	11	1
Fabbri, Guerrina	> 1925	3	1.1	1	0.4	21	1
Fleischer, Editha	< 1925	34	14.0	29	12.3	12	4
Rückert, Lore	< 1925	13	4.7	4	1.5	14	6

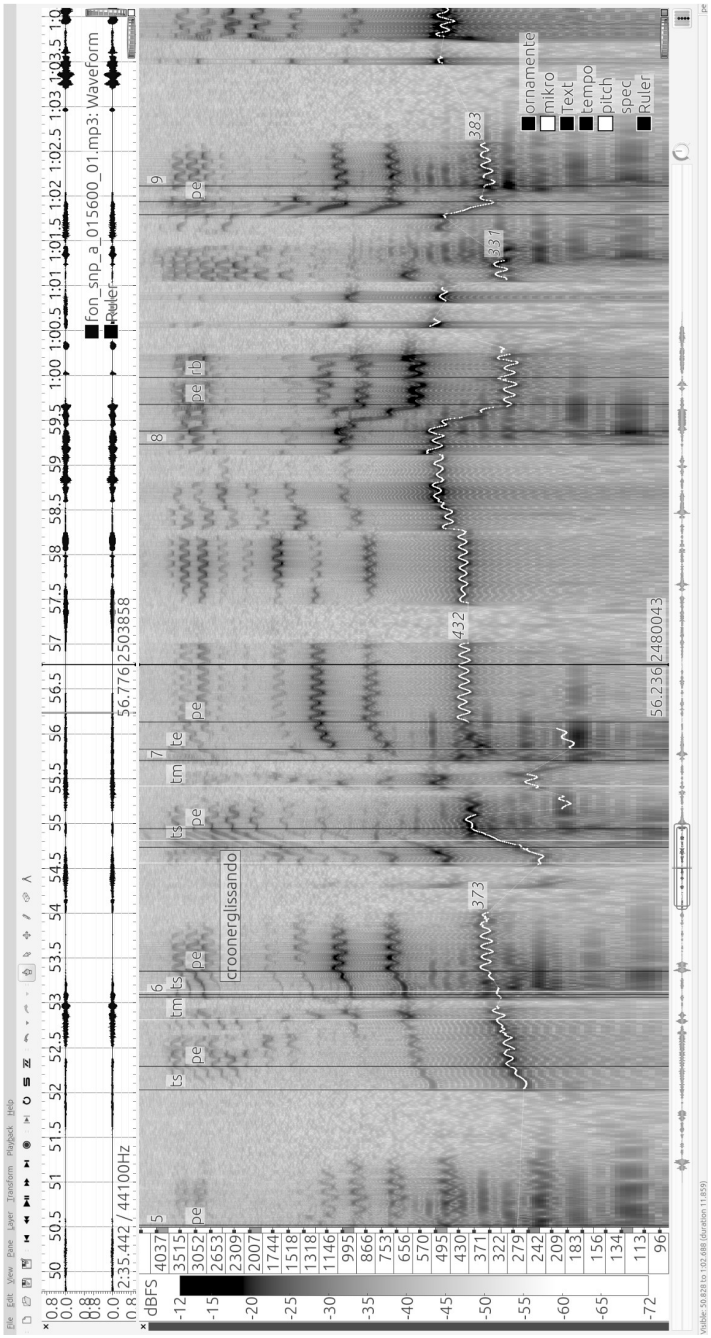
Table 4: Summary of Detail Analysis of »Una voce poco fa« (part I). Rows are sorted according to the year the record was first published. Portamenti Columns (columns three to six) show the total number (n) of all portamenti (column three and four) and their accumulated duration (dur), as well as the number (n) and duration (dur) of all portamenti showing a vibrato as well (+ vibrato, columns five and six).

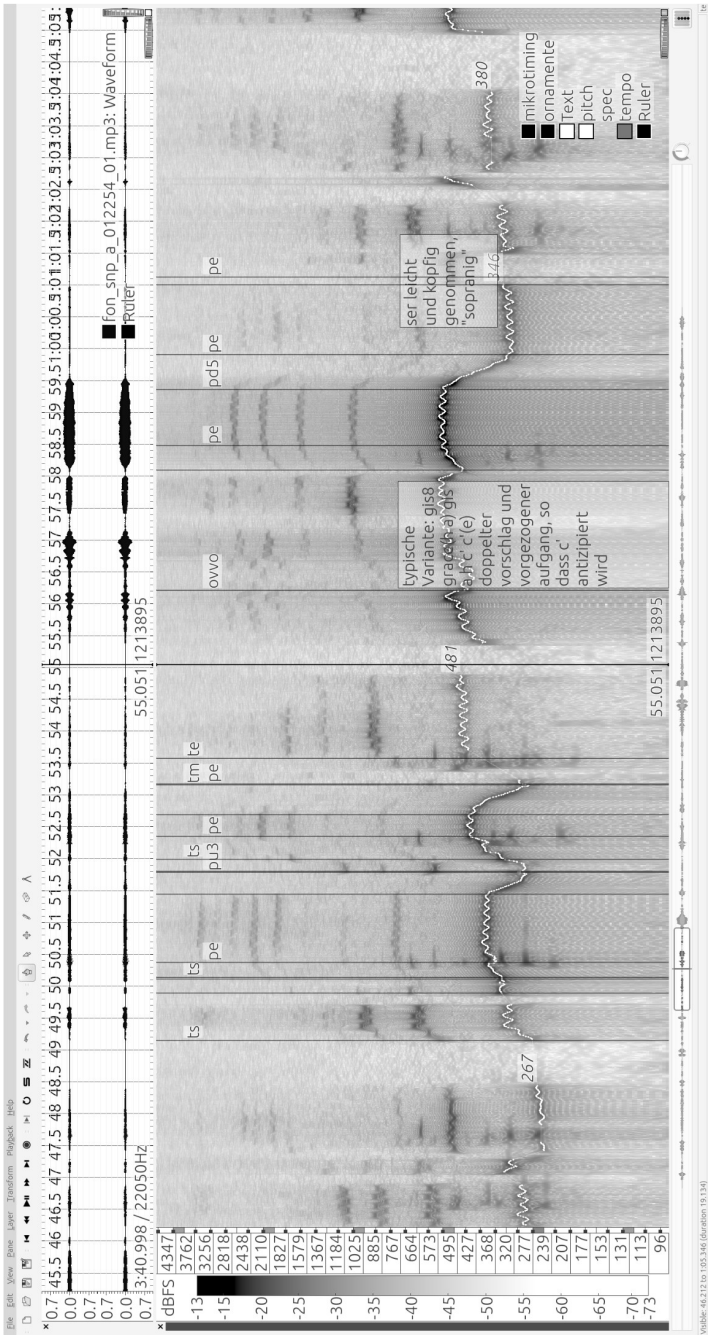
Cat.	Label	Explanation
Portamenti	pu1 pu2 pu3 pu4 pu5 pu6 pu7 pus	*Start position* of a *portamento upwards* with seven characteristics between 1 (very ›right steep‹, *i.e.* an intense increase of pitch at the beginning) and 7 (very ›left steep‹, *i.e.* an intense increase of pitch at the end of the portamento); **pu4** is used for a neutral, *i.e.* nearly linear increase; **pus** is an exception, showing an s-like characteristic (*i.e.* a smooth increasing pitch change, followed by a smooth convergence to the new pitch).
	pd1 […] pd7, pds	*Start position* of a *portamento downwards* with the same seven characteristics plus the s-shaped characteristic.
	puv1 […] puv7, puvs pdv1 […] pdv7, pdvs	The additional **v** denotes that a vibrato is sung with the respective portamento.
	pe	*End position* of *any portamento*. Used to calculate the duration of the portamento. If any start position marker is followed by another start position marker instead of **pe**, the next start position marker is interpreted as **pe**. This happens, if a portamento directly follows upon another. Then, the start position of the new portamento is the end of the former.
Breathing	ae	Clearly perceivable *inhaling* (*Atmer*, *ein*).
	aa	Clearly perceivable *exhaling* (*Atmer*, *aus*).
	aes/aas	the additional **s** denotes a voiced breathing (*stimmhaft*).
Sighing	st	Vocal *tear*, usually a tone-attack sung as if accidentally initiating at the head voice, followed by a clearly perceivable noise or snap into the chest voice. This term is borrowed from Country-Music-singing.
	sb	Vocal *break*, usually a tone ending or interrupted as if accidentally snapping into the head voice, into a noise or into complete silence.
Register	rk	*Head voice* (*Register*/*Kopfstimme*), when used by singers usually using the chest voice (*e.g.* tenors).
	rb	*Chest voice* (*Register*/*Bruststimme*), when used by singers usually using the head voice (*e.g.* sopranos).

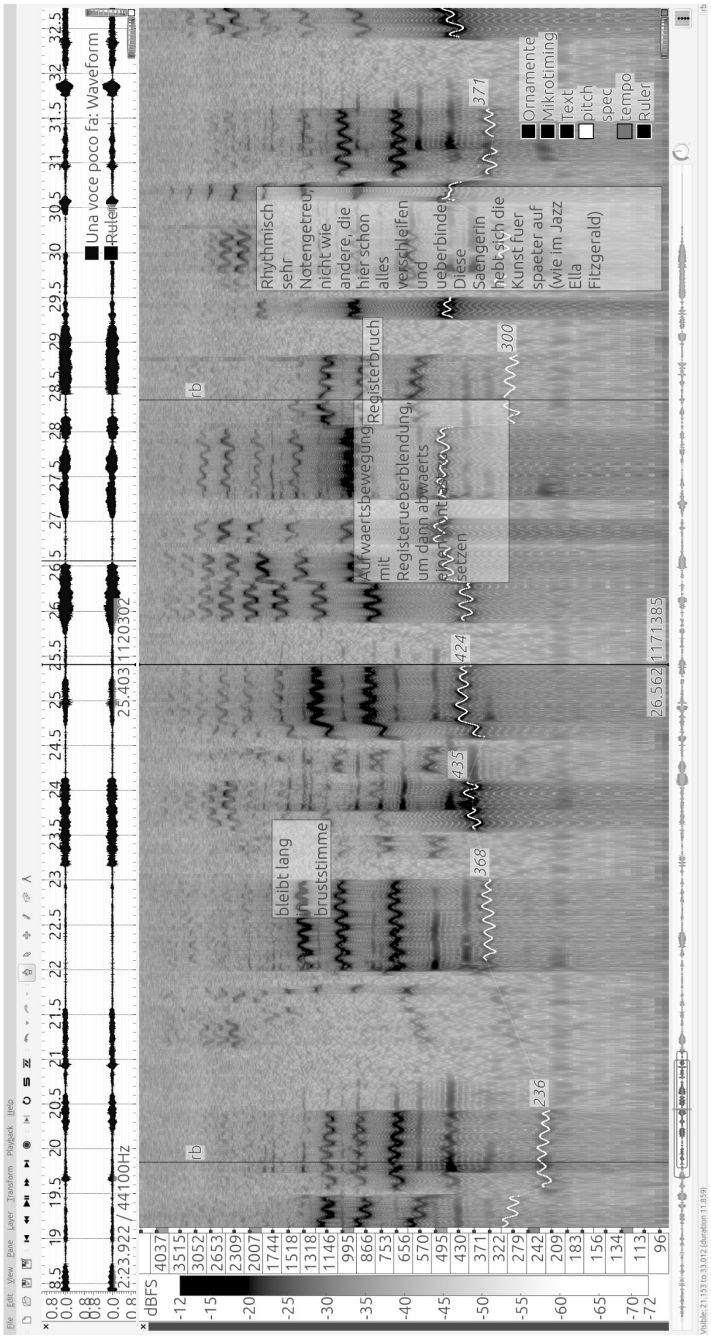
Cat.	Label	Explanation
Musical Ornaments	od	A *passing tone* (*Durchgangston*).
	op	*Inverted mordent* (*Pralltriller*), *i.e.* two tones, a diatonic step upwards and back again.
	opp	*Double inverted mordent*, *i.e.* combination of two succeeding inverted mordents.
	om	*Mordent*, *i.e.* two tones, a diatonic step downwards and back again.
	ov	*Suspension* (*Vorhalt*).
	ovo	*Appoggiatura from above* (*Vorhalt von oben*).
	ovu	*Appoggiatura from below* (*Vorhalt von unten*).
	oo	Tone transposed one *octave* upwards.
	ot	*Trill.*
	os	*Other* (*sonstige*), *e.g.* a short embellishment consisting of several short ornaments; a variance in melody or rhythm which follows the general contour or rhythm of the original.
	oc	*Coloratura*, *i.e.* an intense deviation from the score that usually leads to a substantial increase of measure duration. In some rare cases, the difference between **os** and **oc** becomes somewhat blurred. In these cases the decision for either **os** or **oc** was given reason by using a comment.

Table 5 (pp. 16f.): Label Catalogue. Cat.: categories. Portamenti were subsumed under ornamentation, because they are used as an embellishment depending on the decisions of the individual singer. The use of register contrasts, and other effects like audible breathing and sighing, are ›Non-Verbal Ornaments‹, because they cannot be described by musical notation. Musical Ornaments are embellishments that can be transcribed with musical notation.

Figure 5 (pp. 18–20): Sonic Visualiser screenshots from Supervia (p. 18), Hempel (p. 19) and Tetrazzini (p. 20). Vertical lines are annotation layers for measures, microtiming, portamenti and ornamentation. The text layer shows the comments. All layers used for the analysis are listed at the bottom-right corner of the spectrogram.


fon_snp_a_015600_01.mp3: Waveform
Ruler
2:35.442 / 44100Hz
croonerglissando
373
432
337
383
56.776
2503858
56.236
2480043
ornamente
mikro
Text
tempo
pitch
spec
Ruler


fon_snp_a_012254_01.mp3: Waveform
Ruler
typische Variante: gis8 grace a' gis a h c' c'(e) doppelter vorschlag und vorgezogener aufgang, so dass c' antizipiert wird
ser leicht und kopfig genommen, "sopranig"
mikrotiming
ornamente
Text
pitch
spec
tempo
Ruler


Una voce poco fa: Waveform
Ruler
bleibt lang
in
bruststimme
Aufwaertsbewegung
mit
Registerueberblendung
um dann abwaerts
einen Akzent
setzen
Registerbruch
Rhythmisch
sehr
Notengetreu
nicht wie
andere, die
hier schon
alles
verschleifen
und
ueberbinden.
Diese
Saengerin
hebt sich die
Kunst fuer
spaeter auf
(wie im Jazz
Ella
Fitzgerald)
Ornamente
Mikrotiming
Text
pitch
spec
tempo
Ruler

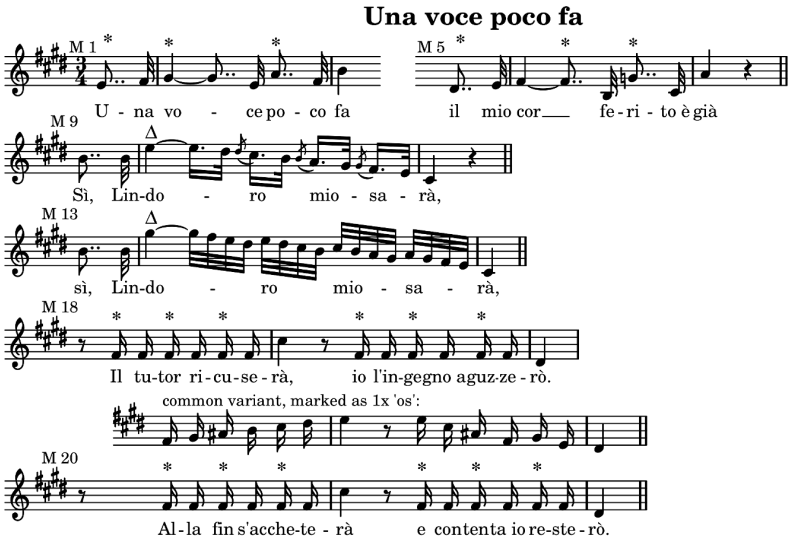


Figure 6: Excerpts from the aria »Una voce poco fa«.[22] Markers indicate microtiming analyses: * = tone proportions, Δ = tone duration. M = number of measure, starting with the first appearance of the vocal part in the aria. Usually, M 20–22 were sung as notated in the variant above, which was then labelled with **oc** (see Table 5).

[22] Based on Rossini, *Il barbiere di Siviglia*, pp. 143–145.