Fusion or separation : From vibrato to vocal trill

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Abstract

The vocal trill, contrary the instrumental one, is nothing but a large vibrato. However, we hear two successive notes instead of a single one. In this study we have made several analysis of the different acoustic parameters of trills recorded by great singers: frequency extent and speed of the trill compared with those of vibrate note of similar frequency, sung by the same singers. By interpreting this lot of data, and using them to produce synthesized vocal sequences, we attempt to answer some questions. What are, if any, the differences between minor and major trills? What is function of the so-called preparation of trill? In what conditions do we tilt from fusion over fission? The results are compared with previous works on fusion/fission perception (Schonle 1980, Nàbêlek 1970).

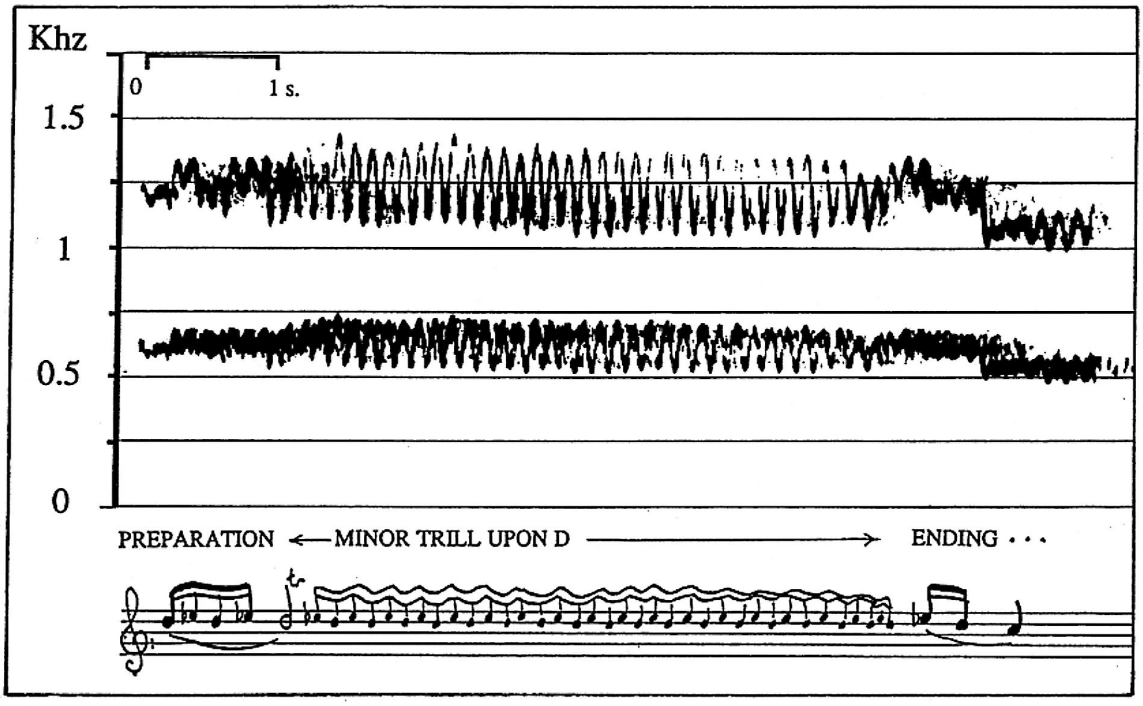

Figure 1: Spectrograghic analysis of a trill sung by J.Sutherland (V.Bellini, la Sonnambula).

Introduction

From the musical point of view, a trill consists of a quick alternation of two notes, a tone or a semitone apart. On an instrument, the trill is produced by alternating two fingering - trombone excepted- and two distinct notes are effectively heard as it is written on a score. But what happens with the voice where a "note" does not correspond to a particuliar geometric configuration, and particularly in bel canto where all notes are vibrated ? Early in 1938 C. Seashore raised the difficult question of pitch perception of vibrated tones without considering the vocal trill. Later W. Vennard (1967) gave spectrographic descriptions of some vocal trills and studied the amplitude modulation. But did not find any extensive acoustical work upon this interesting subject.

Analysis of a vocal trill: the three parts

Let us take, for example, a trill sung by Joan Sutherland in "La Sonnambula" (V. Bellini) and study the frequency/time analysis. [Fig.1]

This beautiful trill, which will serve as pattern for the synthesis, is perfectly performed [*Sound example 1*]. It appears as a very large vibrato, clearly distinguishable from the preparation where the two notes D and Eb alternate slowly (with two or three arches of vibrato on each), and the ending formula on Eb, D and C.

Immediately several questions arise :

- Where are located, in the acoustic signal, the two notes of the trill ?
- In what manner does a trill differ from a vibrato so that we hear two notes instead of one ? Is there a value of the frequency extent for which we switch from fusion to fission ?
- What is the musical accuracy of a vocal trill ?

We shall try to give, in this study, some preliminary parts of the answer.

Trill and vibrato:
comparative measurements of extent and rate of the frequency variations in several singers productions

Trill and vibrato are frequency modulations. To speak about these acoustics phenomenon we use the following words [fig.2]. Δf (in Hz) is the frequency interval between the upper and the lower limit of the frequency modulation. F is the mean frequency (the frequency without modulation). *Extent* of the modulation is the ratio $\Delta f/F$. We can express it in percentage or in cents. As it is well known 0.06 = 100 cents, 0.12 = 200 cents and so on. The *Rate* of the modulation is the number of cycles per second.

By listening to several records of great singers, we pointed out trills and vibrated notes of the same pitch, in the same musical context. Then we made measurements of rate and extent of the frequency modulation and put them in a table [fig.3] .

From left to right we find for the trill, the name of the singer, the trill interval (M for Major and m for minor), the pitch of the main note, the extent, and the rate. We have the same labels for the vibrato, excepted (of course) the interval. Results are seen separately for female and for male singers.

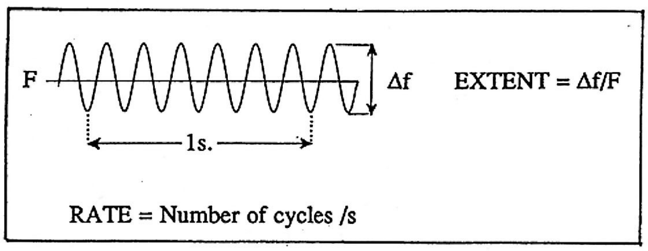

Figure 2: Description of the acoustical parameters.

FEMALE			TRILL			VIBRATO			MALE			TRILL			VIBRATO		
Name	*M*	*m*	*Note*	*Ext.*	*Rate*	*Note*	*Ext.*	*Rate*	*Name*	*M*	*m*	*Note*	*Ext.*	*Rate*	*Note*	*Ext*	*Rate*
J. Sutherland	M		Eb 5	.30	7	Ab 6	.14	5.5	D.Devries	M		C 4	.15	7	C 4	.09	7.5
		m	G 5	.12	8	A 6	.13	6.5			m	E 4	.14	7.5	E 4	.10	7.5
	M		Eb 5	.24	8	Ab 5	.12	6.5		M		G 4	.14	7.5	G 4	.08	7.5
		m	D 5	.27	8	Eb 5	.09	6.5	Escalaïs	M		C 4	.14	6.8	C 4	.10	6.7
C. Deutekom	M		F 5	.23	6.3	Bb 5	.16	6.3	C. Merrit		m	D 4	.17	6.5	Eb 4	.09	5.6
E. Gruberowa	M		C 6	.18	7	F 5	.12	7	A. Endrèze		m	B 3	.13	8	B 4	.07	7
		m	C 6	.13	7.3				Pol Plançon		m	A 3	.20	7.5	D 4	.09	7.5
T. Zylis-Gara	M		Bb 5	.17	7.5	Bb 5	.10	7.5	N. de Angelis	M		G 3	.35	7	G 3	.14	6.5
		m	C 5	.17	7	F 5	.13	6	G. Reinhardt	M		Bb 3	.23	5.8	B 3	.15	6.3
Nelly Melba		m	E 5	.14	6.8	F 5	.06	7			m	Ab 3	.21	5.8	A 3	.17	6
Mado Robin	M		C6	.13	7.5	F 5	.10	7.5		M		G 3	.23	5.8	G 3	.15	6.5
Selma Kurz	M		F5	.18	6	Bb 5	.11	6			m	G 3	.19	5.8			

Figure 3: Measurements of extent and rate of trills and vibrated notes extracted of performances given by female and male singers.

Comparing trill and vibrato rate

According to the singers, there are two groups. For the major part of the singers, the speed of the modulation is approximately the same for the vibrato and for the trill, but some singers exhibit differences. The rate is sometimes greater for the trill than for the vibrato (J. Sutherland) or sometimes weaker (G. Reinhardt).

Comparing the data extent

Looking now to the numerical values of the extent we can see, as expected, that the lowest values are related to the vibrato and the largest one, to the trills. More precisely, when $\Delta f/F < 0.12$ (200 cents) it is a vibrated note, and when $\Delta f/F > 0.18$ (300 cents) it is a trill. But what is surprising, is to find vibrato and trill extent with same values in a large data interval, roughly when $0.12<\Delta f/F<0.18$. There seems to be no difference between females and males.

The first and important conclusion is then : <u>when the frequency modulation interval stands between a tone and a minor third, we may hear either a vibrato or a trill</u>. Or, in other words, we may fuse the frequency modulation in ONE note - that is vibrato hearing - or split the frequency bandwith into TWO separate notes - that is the trill hearing. [fig.4]

The trill threshold; fusion and separation

In 1950 Miller and Heise set a trill threshold with two alternating sinus tones (5/s). When the frequency difference was small, the alternation sounded like a continuous up-and-down movement of the pitch. Increasing the difference, they found a point for which two unrelated and interrupted tones were heard. They called this breaking point "trill threshold". In Miller's experimental conditions trill threshold's extent was closed to 0.15 and constant with the frequency (from 125 to 7000 Hz). Looking back to our results we see that this value, 0.15 goes through the middle of what we may call the common area (vibrato and trill)

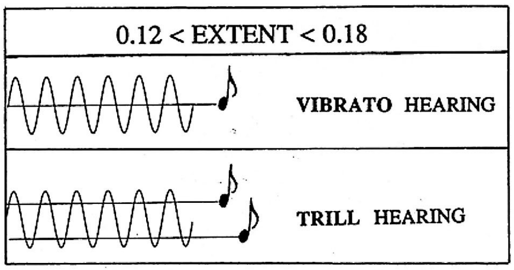

Figure 4: Fusion and separation for same modulation frequency.

In 1976 Shonle and Horan made similar measurements between 250 and 4000 Hz. They gave smaller mean values and found a frequency dependence of the trill threshold : 0.13 for 250Hz, 0.06 for 500 Hz, and 0.03 for 1000 Hz. But they noticed in their conclusion : "The spread in the data is considerable, showing a moderate variation for a given subject and considerable intersubject variation".

As the stimulus of these experiments is an instrumental trill, consisting in two distinct straight tones, it is difficult to take into account the results, to interpret our measurements. We just want to mention that d'Alessandro and Castellengo (1994 found, in an adjustment test using synthetic vibrated tones, a separation situation ("trill hearing") which occurs for $\Delta f/F$ = 0.12, in good agreement with our data extracted from musical performances.

The importance of the context in trill perception

Trill or Vibrato

We saw that extent values between 200 and 300 cents (0.12 and 0.18) were related to vibrated notes as well as trills. To test the role of the musical context we made an experiment using synthetic voice [*sound example 2*]. The hearing of an isolated frequency modulation M (F=554.3 Hz; $\Delta f/F$=0.14; R=7.14) give indifferently the perception of one or two notes. One cannot decide. Now, with exactly the same element (M), we build two phrases :

1) A4, B4,(two crotchets) and M. In this phrase, M become a vibrated C#5.

2) C5,D5,C5,D5,C5,D5,(six semiquavers with accelerando) and M. Now M is a trill and we hear the two distinct notes announced before.

In this short experiment we see the great importance of the context in the musical perception, and the difficulties to "measure" a trill threshold.

- Minor and Major trills

If we examine the table now we can see that, with regard to the extent, the minor and Major trills cannot be separated, either for male nor for female singers. Therefore, <u>the frequency excursion of a trill is not sufficient to perceive the exact interval</u>. In a private recording, at the laboratory, a professional singer (soprano) gave us a clear example of minor and major trills. These were effectively very clear for the ear, but measuring the extent was troublesome at that time (1965) because the frequency extent was exactly the same for the minor and for the major trill ! In this case, context is given by the preparation. The two future notes of the trill interval are sung without vibrato, and with amplitude reinforcement. [Sound example 3]

Conclusion :
Some guide to hear clearly a vocal trill

In music the trills are employed in two ways (Colas & coll. 1994). First as an embellishment of the melodic line, among appoggiaturas, turns, shakes and other grace notes for which emphasis is not put on pitch definition. These trills are short and generally without terminiation. On the other way the trill has an harmonic function. We find it generally at the cadence, when the singer is a capella. And as a final signal it must be unambiguous.

To hear clearly such a trill, several "aids" can be find :

1 - Frequency extent of the trill must be at least of 0.12 to allow the separation, or, in other words, larger than the currently vibrated notes.

2 - As the perception is always a relative process, the notes involving the trill, particularly those of the preparation, must ve very weakly vibrated. This constrast facilitates the separation.

3 - The trill begins with a preparation which is an announcement of the true musical interval, major or minor second, and ends with a termination which reinforces the perception.

4 - The musical context announces a trill : because of the harmonic cadence, or by imitation of an instrument.

Finally the acoustical study of the vocal trill perception leads us to put several questions as matter for further works. The most important one is that we don't know what are the real perceived limits of the frequency excursion, and if Δf must be reduced to represent the musical interval that we hear. The perception of the accuracy of the trill interval must be tested in and out musical context, and also the effect of the amplitude modulation associated to some trills.

Aknowledgments

We should like to thanks G. Reinhardt who kindly came to our laboratory to give some beautiful trill examples.

Extent < 0.12 *200 cents*	**Only VIBRATO** 0.12 seems to be a lower limit for fission
0.12 < Extent < 0.18 *200 cents* *300 cents*	**Both TRILL and VIBRATO** but each singer makes differences between Trill and Vibrato.
0.12 < Extent < 0.24 *200 cents* *400 cents*	**MAJOR and MINOR TRILLS Mixed** Extent vary with - musical character - voice type

Figure 5: Some conclusions about extent measurements and vocal trills. The numerical values give approximate borders.

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