ACOUSTIC CHARACTERISTICS OF VIBRATO ONSET IN SINGING

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ABSTRACT

A study of the first five cycles of vibrato production ("vibrato onset") in five male singers suggests that there is considerable variety in such variables as vibrato range, vibrato cycle, onset excursion and timing of appearance of initial F0 and energy peaks among both trained and untrained voices. Vibrato onsets serve as a diagnostic for overall setting of individual singing mechanisms just prior to voice production and also suggest that this overall setting is an important factor in establishing a good vibrato.

1. INTRODUCTION

This study examines the onset of vocal vibrato in the production of five singing voices that range from highly trained to untrained. We attempt to describe some characteristic of vibrato onset and to determine from acoustic data of the onsets some implications for a theory of vibrato production,.

Perceived vibrato in singing results from periodic frequency and amplitude modulation of the voice. It is well established that periodic frequency modulations of approximately 5 - 7 Hz are necessary for a tone to be perceived as vibrato; less modulation is heard as periodic pitch change while more is heard as a tremolo or even a wobble [1]. A great many issues revolve around vibrato, most of which we ignore here in favor of our deliberately narrow topic.

Sundberg [2] deconstructs vibrato into four variables: rate, extent, regularity, and waveform. However, few researchers have focused on what we call the *vibrato onset* (VO) — the frequency and amplitude characteristics of the voice at the very beginning of a vibrato tone. We narrow this broad definition by referring to the excursion of pitch at the beginning of a vibrato tone as VO (exc). Seashore [3] claims that rising VO (exc) is a natural physiological necessity. In this paper, we quantitfy VO (exc) as the movement of the initial vibrato pitch (in Hz) into the mean of the first five vibrato cycles. The relationship between the first vibrato pitch peak and the first enegery peak of the onset is called the peak index VO (PI). Extent of vibrato will be referred to as vibrato range and frequncy of the vibrato during the first five cycles as the vibrato cycle.

2. SUBJECTS, DATA, ANALYSIS

Four male singers were recorded in an anechoic booth at the University of Calgary on a Sony DAT using an AKG studio microphone. One subject was recorded in a sound-proof studio at the University of Victoria (B.C.), using an AKG C1000S microphone and a Sony DTC-750. Vocal production consisted of four short staccato tones followed by a held tone on D4 and A3, each group being produced on the vowels [i] [e] [a] [o] after warmup. In the case of one singer, recordings were made before warmup and, on another date, after warmup. Falling arpeggios on a major chord from D4 - D3 were also produced on the same vowels. All subjects were asked to sing at *mf*. The held tone on A3 and lowest arpeggio tones on D3 were used as the data for analysis.

Data was digitized at 44160 Hertz on a Kay CS model 4300. An overall examination of the data was followed by filtering with a Blackman low pass filter and then downsampling to 20480 Hertz. Impulse markers were added to the signal and pitch analysis carried out with CSL software Version 5.07. The first five pitch cycles of the vibrato tones were analyzed. The following variables were transferred to data sheets and then to Microsoft Excel spreadsheets: subject, sung pitch, vowel, mean F0, mean frequency, median frequency, STD for frequency, frequency range, energy and energy range, F0 onset, energy mean, location of first F0 peak in ms from the beginning of the sample, location of first energy peak in ms from the beginning of the sample, time of the five cycles in ms; from this last data, the Hertz value for vibrato periods was computed.

Voices used in the study are presented in table 1.

voice	status	study years	career	notes
db baritone	pro	15+	40+ years	no warmup
db2 baritone	pro	15+	40+ years	warmup
tv baritone	st.	5	local chorus	warmup
jg tenor	st.	> 2	local chorus	warmup
mb baritone	chorus	1	20+ chorus	warmup
mr baritone	actor	1	-	warmu p

Table 1. Voices in this study.

Singer db (= db2) has had an extensive professional career in opera and concert singing. Singer tv is a talented student who has worked with his teacher for nearly three years. Singer jg is a young student who has sung in high school chorus but who has just begun to study singing formally. Singer mb had extensive experience in choral singing but has not sung with any groups for some 15 years. Singer mr is an actor who has virtually no formal training in singing or choral experience.

3. GENERAL OBSERVATIONS

3.1 Vibrato range and mean (Hz)

We first present data on the overall range of vibrato for each speaker, as the range will be relevant to calculation introduced below.

Voice	Avg. Range (Hz)	Avg. Range (Hz)	Ave. STD (Hz)	Ave. STD (Hz)
	D3	A3	D3	A3
db	-	68.75	-	14.68
db2	41	42	8.34	12.11
tv	26	52.5	5.74	7.92
jg	20.67	18.5	4.11	2.93
mb	15.5	29.5	3.54	4.83
mr	17.33	32.25	3.34	5.52

Table 2. Range and STD of vibrato and tone by speaker

Mean frequency of tone for each voice, all vowels, is presented in table 3.

Voice	D3	A3
db	-	211.82
db2	141.99	213.97
tv	130.65	205.27
jg	143.31	213.61
mb	145.51	219.11
mr	147.51	213.55

Table 3. Mean F0s of vibrato tones.

Given that the equal-tempered values for these tones are and D3 145.83 Hz and A3 220 Hz, these figure confirm that vibrato depresses pitch [4].

3.2 VO (exc)

Recall that we define vibrato onset excursion as F0 movement into the mean of the first five vibrato cycles. Overall, rising VOs are characteristic of 81% of these vibrato productions. Consistently falling VO is only found in voice jg, and for this voice, only on A3. It should also be noted that the falling VO on db2's A3 was only -0.14 Hz and on mr's A3 -0.38 Hz. In contrast, voice jg's average VO fall was 10.38 Hz and ranged from -16.03 Hz to -5.78 Hz.

3.3. Vibrato cycles

Table 5 presents the figures for the first five vibrato cycles in Hz (cps = 1/T).

Voice	D3	A3
db	-	4.41
db2	4.86	4.60
tv	6.07	5.89
jg	5.93	7.12
mb	5.38	4.88
mr	6.43	7.20

Table 4. Vibrato cycles.

These figures clearly show the rather rapid vibrato of the untrained voice jg and the actor mr. They do not index, however, another important characteristic of gross VO — the time it takes for a vibrato to "settle in" to a steady cycle. Not surprisingly, this was found to be more variable among less trained than among more trained singers.

3.4. VO (exc) averages by tone

Table 6 shows VO (exc) averages for D3 and A3. Recall that VO (exc) is the range of VO excursion found by subtracting the first pitch (in Hz) of the VO from the mean Hz of the first five vibrato cycles. We are aware that computing the mean for the first five vibrato cycles includes the VO excursion, thus depressing the figure for mean Hz with rising VO excursions and raising the mean Hz figure for falling VO excursions. However, spot checks against figures obtained by using the last four vibrato cycles as the basis for establishing mean F0 of the tones showed only small differences in Hz values, so we continued to use all five cycles. For voices with only one falling VO, that fall is not computed in the average.

Voice	D3	A3
db	-	33.57
db2	5.24	12.47
tv	13.98	39.52
jg	7.31	-10.39
mb	5.01	14.86
mr	10.51	19.55

Table 5. VO (exc) averages by tone.

It is perhaps noteworthy that all VO excursions are less wide on the lower pitch.

3.5. VO (PI): Peak Index

Instigating a vibrato requires not only control of pitch, but of breath, which translates into energy measurable in dBs. We examined the coordination of these two factors through a calculation we call peak index VO (PI). A positive PI indicates that the F0 peak precedes the dB, e.g. singer db/A3/[i] shows the first F0 peak 0.092 ms and the intial dB peak 0.179 ms after the beginning of voice production; the PI is this 0.087 ms. Table 6 provides data on averaged PIs for all subjects.

Voice	D3	A3
db	-	0.055
db2	0.029	0.028
tv	0.022	0.067
jg	0.013	0.068
mb	0.032 1 PI = -0.151	0.096 2 PI = -0.098
mr	-0.08 1 PI = 0.007	0. 005 2 PI = -0.036

Table 6. VO (PI) (averages)

4. PROFILES

Table 7 provides a cross-comparison of voices for the variables presented above. A brief description of each singer's VO production follows.

Voice	Vibrato range avg. in Hz. D3	VO excursion avg. in Hz D3	VO (PI) D3	Vibrato cycle avg, in Hz D3	Vibrato range avg. in Hz. A3	VO excursion in Hz A3	VO (PI) A3	Vibrato cycle in Hz A3
db	-	-	-	-	68.75	33.57	0.027	4.41
db2	41	5.24	0.029	4.86	42	12.47	0.028	4.60
tv	26	13.98	0.022	6.07	52.5	39.52	0.067	5.89
jg	20.67	7.31	- 0.013	5.93	18.5	-10.39	0.68*	7.12
mb	15.5	5.01	0.032*	5.38	29.5	14.86	0.096**	4.88
mr	17.33	10.51	(-0.08)*	6.43	32.25	19.55	0.005**	7.20
group average	**24.1 Hz**	**8.41 Hz**	**0.028 ms** (pos. only)	**5.73 Hz**	**40.58 Hz**	**21.73 Hz**	**0.155 ms**	**5.68 Hz**

Table 7. Singer profiles for four variables, both tones. Number of ± PI values excluded from the calculation is indicated by asterisk.

5. DISCUSSION

5.1 Singer profiles

The data in Table 8 allows us to sketch an overall profile of each voice with respect to vibrato onset. Note intially that the vibrato cycle average lies in the 5 - 7 Hz range assumed to be natural for "true" vibrato.

5.1.1. db. D3 no data

A3: Range is wide and cycle somewhat slow, with large excursion well above group average.

5.1.2. db2. D3: Still wide in range, but vibrato cycle is below group average; excursion is rather narrow.

A3: Range is at group average and cycle is slow; excursion is narrow; overall, impressionistically good.

5.1.3. tv. D3: Range is at group averge, excursion is well above average, though approximately half the range value, indicating that it begins at roughly the level at which the lowest pitch troughs occur; cycle in the midddle of the 5 - 7 Hz zone, and not impressionistically rapid.

A3: Range and excursion above average; vibrato cycle at group average.

5.1.4. jg. D3: Range and excursion below group average, impressionistically narrow; cycle is close to middle of 5 - 7 Hz. zone.

A3: Range well below group average, narrow falling excursion and rapid cycle; only tone in which PI is well off group average — misalignment is 0.68 ms, indicating poor control of pitch and breath coordination for this tone. Impressionistically tending towards *voce di capra*.

5.1.5. mb. D3: Range narrow, below average excursion combined with near average cycle.

A3: Range some 25% below group average, rather narrow excursion; cycle slightly below the 5-7 Hz. zone.

5.1.6. mr. D3: Narrow range, slightly above average excursion combined with cycle that approaches upper boundary of the 5 - 7 Hz. zone; small negative PI.

A3: Much wider range and excursion than for D3, though excursion approaches group average; rapid cycle, very low PI.

5.2 VO (exc)

Comparing data for vibrato range and VO (exc) averages in Table 7, we see that wider range of vibrato is generally preceded by a greater rising or falling VO excursion. For D3, this relationship holds except for db and to a very slight extent for jg. For A3, this holds except for db2.

Averages reflect this relationship; the D3 average excursion is, however, about a third of the average range, while the A3 excursion is over one-half. These numbers grossy outline the relationship between VO and range of vibrato. A better reflection of what VO is like for different ranges of vibrato and different voices than the averages of Table 9 is obtained by comparing what per cent of the range and/or mean the VO makes up. Table 8 shows these figures.

As a case in point, we note that voice db2/A3 shows a VO (exc) that is 29.69% of his total range on that tone. His VO (exc) as % of the mean for the same tone is 5.38. Compare this with singer jg's excursions as % on the same tone: his excursion is a larger percentage of the total range of vibrato (56.16%) , even though it is narrow and quite close to the mean (4.86). The two voices are not widely differing in excursion as % of the mean, even though the starting points for the excursions are quite different in terms of vibrato range. This reflects the general wideness of vibrato in the case of db2 and its narrowness in the case of jg.

Voice	Vibrato range mean in Hz. D3	VO (exc) as % of mean range: D3	Mean F0 of vibrato D3	VO (exc) as % of mean F0 D3	Vibrato range mean in Hz. A3	VO (exc) as % of mean range A3	Mean F0 of vibrato A3	VO (exc) as % of mean F0 A3
db	-	-	-	-	68.75	29.69	211.82	15.85
db2	41	12.78	141.99	3.69	42	39.69	231.97	05.38
tv	26	53.77	130.65	10.70	52.5	75.28	205.27	19.25
jg	20.67	35.37	143.31	5.10	18.5	56.16	213.61	4.86
mb	15.5	32.32	145.51	3.44	29.5	50.37	219.11	6.78
mr	17.33	60.64	147.51	7.12	32.25	60.62	213.55	9.15

Table 8. Average VO excursions expressed as per cents of averaged vibrato range and averaged vibrato tone means.

5.2.1. VO excursions as % of range. These figures show that for most voices in this study, there is no obvious correlation between vibrato range and mean VO excursions expressed as % of vibrato range. Indeed, our two "best" voices show quite different figures for mean VO excursions as % of range: db2, D3 (12.78); db2 A3 (29.69) and tv, D3 (53.77); tv A3 (75.28). The most consistent figures for mean VO excursions as % of range come from the least trained voice, mr (60.64 and 60.62).

5.2.2. VO excursions as % of mean F0 of vibrato tones. Here, too, we see considerable variation in VO excursion means expressed as per cents of mean F0 of the tones. Voice db2 maintains a fairly narrow range of excursion relative to the mean H0 of the first five vibrato cycles between 3.69 and 7.19 per cent Beginner jg hovers around 5%, showing that his narrow range of vibrato is matched by a narrow excursion. Voice mr's even narrower range of vibrato on D3 shows an excusion per cent of 7.12, while his considerably wider range of 32.25 Hz on A3 shows an excursion per cent not much above his D3 value at 9.15%.

We cannot say, therefore, that a narrow excursion is necessarily as sign of a "good" VO; it may well be a sign of a generally narrow range arising from vocal tension, as in the case of voice jg, or it may be a sign of good vibrato control, as in the case of voice db2/A3. On the other hand, voice tv's rather wide excursion precentages relative to the mean F0 of the tones examined did not strike our ears as excessive or unpleasant.

5.3. Peak Index

Finally, we note that PI indexes show that arrival of first F0 peak and first energy peak are in general very close. We note that voice db2 shows greater consistency in coordinating these events that the other voices. We cannot comment at this time on the statistical significance, if any, of these differences.

6. CONCLUSIONS

The data shows both consistency and inconsistency of VOs. When the vibrato is consistently narrow and rapid, we saw a tendency for consistently short excursions. This arises from hypertension of both body and breath. Inconsistencies in VO arise from a lack of control of coordination of breath, posture, and glottal closure.

These explanations may be familiar to voice teachers. We have shown here that these problems are present in the very earliest milliseconds of vibrato onset.

Secondly, we feel that the data for db versus db2 (pre- and post-warmup by professional), suggest that the involvement of the whole muscular system is critical to good vibrato production, and that whatever neuromuscular controls of vibrato are involved in vibrato production, they must be part of a larger picture that includes the correct setting and a properly prepared muscular system.

We conclude that problems in voice production as a whole, including vibrato, are present in the onset of vibrato tones, where pitch accuracy, regulated vibrato, and consistency of timbre will all be lacking, and that this generalized failure to initiate vibrato correctly results from a failure in the overall vocal setting for vocal production. Thus, we feel that focus on the individual actions of certain laryngeal muscles, e.g., the cricothyroids, which is obviously important to vibrato production and to vibrato research [4] can be extended by focus on the overall setting, which is manifested in vibrato onset.

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