VIBRATO: QUESTIONS AND ANSWERS FROM MUSICIANS AND SCIENCE

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INTRODUCTION

Vibrato is the periodic fluctuation in pitch, amplitude and/or timbre of a musical tone. It is used by singers, string players, and, in some cases, by wind instrumentalists to ornament or color a tone. Vibrato research has focused on the general characteristics of vibrato, such as its form (generally found to be sinusoidal, but mostly trapezoidal according to Horii, 1989b), its perceived central pitch (mean or median of pitch fluctuation, see, e.g., Shonle & Horan, 1980, Sundberg, 1978), and its mean rate and extent in musical performances (rate between 5.5-8 Hz, extent between 0.6-2 semitones for singers and between 0.2-0.35 semitones for string players, see Seashore, 1938; Sundberg, 1987; Meyer, 1992). The modeling of vibrato characteristics has suggested that pitch vibrato is the primary acoustic characteristic of vocal and string vibrato from which amplitude and timbre vibrato result (Horii, 1989a; Meyer 1992). The (un)conscious control of vibrato characteristics by professional musicians has been a point of debate. While string instruments are generally found to be able to control vibrato rate and extent, singers are said to have very limited to no control, or to have only some control over vibrato extent (Seashore, 1932; Sundberg, 1987; King & Horii, 1993). Analyzed dependencies of vibrato to other performance aspects are (among others): short notes only contain an upper arch (Castellengo, Richards & d’Alessandro, 1989); notes generally start with a rising pitch (Horii, 1989b) and end in the direction of the transition (Sundberg, 1979). Equal debate concerns the dependency between vocal vibrato and pitch height, which is confirmed by Horii (1989b) and rejected by Shipp, Doherty & Haglund (1990).

In this paper, we will focus on vibrato as an expressive means within musical performances. In this respect, we assume that vibrato may be used by musicians to stress notes or to convey a certain musical interpretation. It is an area of research that recently gained interest and is still in an explorative stage (see the contribution of Gleiser & Friberg to this proceedings). We turn to musicians' hypotheses concerning the expressive function of vibrato and compare this to observations made on the relation between music structural characteristics and vibrato rate and extent in actual performances. The analyses of the performance data are based on the predictions of expressive vibrato behavior (Sundberg, Friberg & Frydén, 1991) and on predictions stemming from piano performance research that attributes expressive behavior to the pianist's interpretation of musical structure (e.g., Clarke, 1988). The comparison aims to show that the scientific inquiries could be inspired by hypotheses stemming from musicians/experts who devote their life to refining their control of musical parameters for expressive means, and teaching that to students. Vise versa, the scientific results can achieve a musical meaningfulness and value, also for musicians and teachers.

METHOD

Subjects

Five professional musicians participated in the study: a cellist, an oboist, a tenor, a thereminist, and a violinist. The musicians are all known-musicians for their performance in orchestras, chamber ensembles and/or as soloists. Each participant was paid for participation.

Material

The study used a notation of the first phrase of ‘Le Cygne’ by Saint-Saëns (1835-1921) for musicians to play from. Originally, 'Le Cygne' (translation: the swan) is for cello solo with orchestral accompaniment. A piano reduction of the orchestral accompaniment is however very common, as is a performance of the solo part by other melodic instruments than cello.

The swan is in G major and 6/4 measure. The first phrase is the theme of the piece, is four measures long and consists of two sub-phrases of two bars. It is preceded by an introduction from the accompaniment of one bar (see figure 1). The melody of the first sub-phrase starts with a descending movement in quarter notes (measure 2) and ends with a counter-movement in longer notes. The melody of the second sub-phrase consists of one long ascending movement in eighth notes that starts and ends on a dotted half note (m3, figure 1). The accompaniment consists of broken chords in sixteenth notes. The harmony of the broken chords is: the tonic chord in root position (m1-2), the ii sub-dominant chord with a pedal on G in the bass (m3), a progression from ii to dominant-7 chord with a pedal on G in the bass (m4) and a return to the tonic in root position (m5).

The questions of the interview concerned the production of vibrato on the musician’s instrument, the general use and function of vibrato, the specific expressive treatment of the first phrase of ‘Le Cygne’, and the differences in this treatment between repetitions. Expressive treatment includes variations in amplitude, vibrato (general), and vibrato rate & extent.

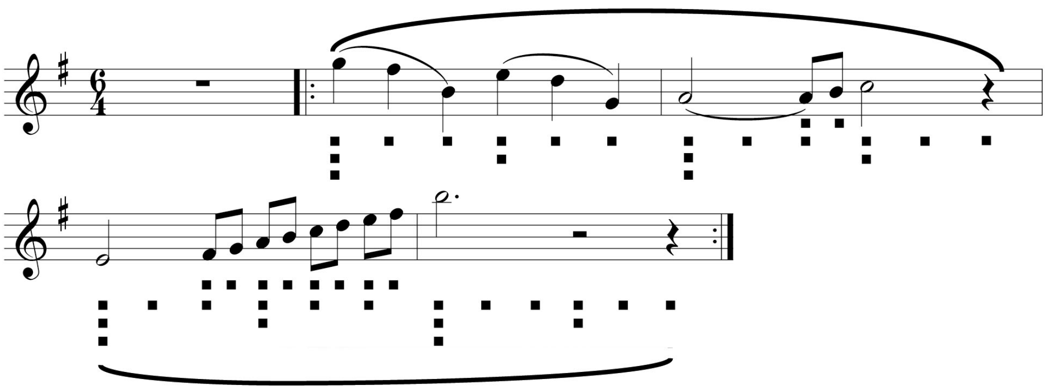

Figure 1 Score of the first phrase of ‘Le Cygne’ with annotation of metrical structure (dots) and sub-phrase structure (bold lines).

Procedure

The musicians performed the first phrase of ‘Le Cygne’ by Saint-Saëns along with a metronomical accompaniment, which they heard over headphones. They performed the phrase six times after each other without pauses. The tempo of the accompaniment was fixed at 60.0 beats per minute. This fixation of tempo was chosen to limit the use of expressive timing and encourage the use of expressive vibrato. Changes in dynamics were left free. The performance took place in a sound proof cabin and was recorded as 11 kHz, 16-bit, mono audio files.
After the recording session each musician was interviewed. The interview was recorded on video. The musicians were free to show examples on their instrument and to drift away from the exact question to some extent.

Data processing

A spectral analysis was run on each file, the fundamental frequency was extracted and half-cycles were detected between subsequent local maxima and minima. The half-cycles were interpreted as vibrato when their rate was within the range of 2-10 Hz and their extent was larger than 0.1 semitone. Note on- and offsets were detected on the basis of a dynamic amplitude threshold (less than -40 dB as compared to the maximum amplitude) in combination with a dynamic pitch threshold (less then 0.3 semitone deviation from the mean pitch). The resulting data to be analyzed consisted of collected note features: mean amplitude, mean vibrato rate of pitch vibrato, and mean vibrato extent of pitch vibrato per note.

RESULTS INTERVIEW

Cello

According to JI, vibrato is made on a cello by moving the left hand in a periodic and symmetric way up and down the neck of the instrument around a central pitch. The impulse is rather large and comes from the arm. Vibrato is according to JI quite natural and easily learned. He saw the function of vibrato in ‘Le Cygne’ as aid in the production of a legato performance, and of a warm and lyrical sound. Vibrato was used as part of the phrasing of the music. He used a kind of vibrato that is not too fast and not too exuberant. Some notes of the phrase got stress by giving them a more full sound, which means that he performed those notes with a more expressive and faster vibrato, and with more “meat” of the fingers. The end of phrases “died” away, which was accompanied by a smaller vibrato. In general no note was performed the same or with equal vibrato.

Oboe

According to HR, vibrato on an oboe can be made in several ways; by using the throat, the diaphragm, or even the lips or jar. HR used throat vibrato in ‘Le Cygne’, because it is quite fast and expressive. Throat vibrato is produced by a rapid repetition of a short ‘a’ sound on the oboe. She teaches her pupils to perform a rhythmically and fast vibrato by synchronization with a metronome. The result is a periodic fluctuation in pitch around a stable pitch center.
HR used small vibrato in her performance of ‘Le Cygne’ is, because of its soft and subtle character. She gave the first note and the fourth note more vibrato than the other notes of the first bar. In the second bar, she played the a’ intense and relaxed towards the end of the sub-phrase. The next e’ got considerable vibrato, the following eighth notes did not get vibrato, but “bellies”, and the last note got extra vibrato. Dependencies between vibrato and other performance aspects are, according to HR: vibrato rate and extent increase with the resistance of a tone, vibrato rate increases with the loudness of tone and is influenced by the rhythm of the accompaniment.

Tenor

According to AO, a singer will naturally sing with vibrato if he or she breaths correctly and the air flows fluently. So, AO does not produce vibrato, instead he let it come naturally as a result of natural singing. In the recording session, he had to sing ‘Le Cygne’ on a single vowel, so without text. He found this a bit unnatural. AO sang the entire piece with the same vibrato, the only differentiation that he made is one of stopping or starting the vibrato. The first measure, he performed legato, which naturally included vibrato. The long a’ of the next measure got vibrato only halfway. He decreased loudness towards the end of measure two, to start anew at the e’ in the next measure. Then the music built up (loudness) towards the high b’’. The eighth notes hardly got any vibrato, because vibrato is too slow. Vibrato may become slower with increasing pitch height and faster or wider with increasing loudness.

Theremin

A theremin is an electronic instrument controlled by moving both hands towards two antennas. The left hand determines the loudness and the right hand controls the pitch of the electronically generated tone. According to LK, finger positions include all positions between a closed hand (finger position 0, relative low tone) and an open hand (relative high tone). She makes vibrato by moving her hand to the left and to the right, which constitutes one vibrato cycle. The start is at the minimum pitch, which equals, according to LK, the perceived pitch of the note. The general vibrato principle is to let the vibrato and volume change together. This means that a note starts soft and without vibrato and then builds up in volume and vibrato. In ‘Le Cygne’, LK used lyrical vibrato, which is fast and wide and differs from melancholic, expressive, or nervous vibrato. The shorter notes in the piece did not need much vibrato; longer notes did. The function of vibrato was expression. Special treatment of notes was done (however) by playing without vibrato. For example, LK gave the long a’ a long start without vibrato.

Violin

As RK told us, the vibrato on a violin is made by rotating the fingers of the left hand up and down the neck of the violin. This movement is a regular movement around a central pitch and is controlled either by the fingers, hand or arm, or a combination of the three. RK himself has arm-vibrato. RK performed ‘Le Cygne’ with relative large vibrato, like a cello and less like a violin. The function of vibrato was to color the tone. The first two measures were in his opinion quiet, while the second two measures were more intense. This, he wanted to reflect in his performance: first measure: a calm and fluent movement; second measure: leaning on long a’ and relaxation towards the end; third and fourth measure: in general faster vibrato, leaning on e’ and scale with equal intensity.

RESULTS DATA ANALYSIS

The collected note features (which include mean loudness, mean vibrato rate and mean vibrato extent per note) were analyzed in relation to the musical structure of the first phrase of ‘Le Cygne’. Three structural descriptions were used in the analysis: a description of metrical stress, position of the note within a phrase and melodic charge.

Table 1

Coding of the notes within the analysis along three structural descriptions (metrical stress, phrase position and melodic charge).

Note	Coding in analysis		
Pitch	Metrical stress	Phrase position	Melodic charge
g’’	0	0	0
f#’’	2	1	5
b’	2	1	4
e’’	1	1	3
d’’	2	1	1
g’	2	1	0
a’	0	1	2
b’	3	1	4
c’’	1	2	(-) 2.5
e’	0	0	3
f#’	2	1	5
g’	3	1	0
a’	1	1	2
b’	3	1	4
c’’	2	1	(-) 2.5
d’’	3	1	1
e’’	2	1	3
f#’’	3	1	5
b’’	0	2	4

The metrical stress is related to the metrical hierarchy of ‘Le Cygne’ which is indicated in figure 1 and follows the metrical indication at the start of the piece and a hierarchical model, such as described by Lerdahl & Jackendoff (1983). Metrical stress increases with metrical hierarchy (for the coding of individual notes see table 1) and the prediction would be that vibrato rate and extent increase with metrical stress. For the phrase positions, we separated the start (first note), middle and end (last note) of each sub-phrase (see table 1). This is in line with descriptions of rhythmic structure as groupings starting and ending with a structural downbeat (e.g., Cone, 1968) and with a common finding in performance literature that performers tend to mark phrase boundaries (Palmer, 1989). The melodic charge of notes is coded according to Sundberg et al. (1991). Melodic charge increases with increasing distance between the melody note and the tonic note of the prevalent key (G major). The prediction is that the vibrato rate and extent, as well as the loudness of notes increase with increasing melodic charge. Each note is given a relative level of melodic charge (see table 1). Below, we report the results of three different ANCOVA's. In each analysis, the independent variables are metrical stress (nominal), phrase position (nominal) and melodic charge (continuous). The dependent variable is mean vibrato rate per note in the first ANCOVA, mean vibrato extent per note in the second ANCOVA, and mean amplitude per note in the last ANCOVA.

Effect of musical structure on vibrato rate

The combined effect of metrical stress, phrase position and melodic charge on vibrato rate is significant for all instruments ($11.8 < F(6) > 22.1$, $p < 0.0001$), except for the tenor ($p > .05$). This effect is strong for the cello, oboe, theremin, and violin (R squares are between 0.42 and 0.52).

The individual effect of meter is significant for the cello ($F(3) = 10.8$, $p < 0.0001$), oboe ($F(3) = 10.7$, $p < 0.0001$), theremin ($F(3) = 8.8$, $p < 0.0001$) and violin ($F(3) = 17.1$, $p < 0.0001$). The effect on vibrato rate is, for the oboe and violin, such that in average the vibrato rate increases with decreasing metrical stress. For the cello, the vibrato rate is in average faster for notes on the metrically weakest position than for notes at other metrical positions. For the theremin, the vibrato rate is generally high for notes on a metrically weak position, low for notes on the strongest metrical position and intermediate for notes with intermediate metrical stress. This is contrary to the prediction that vibrato rate and extent increase with metrical stress.

The individual effect of phrase is significant only for the theremin ($F(2) = 9.9$, $p = 0.0001$). This effect of phrase position is notable in a slower vibrato rate at the end of phrases.

The individual effect of melodic charge is significant only for the violin (F (1) = 5.7, $p < 0.02$). The vibrato rate generally increases with melodic charge.

Effect of musical structure on vibrato extent

The combined effect of musical structure on vibrato extent is significant for all instruments (3.9 < F (6) > 15.3, $p < 0.0001$). The effect is strong for the violin (R square = 0.49), small for the theremin (R square is 0.18) and intermediate for the cello, oboe and tenor (R square is between 0.28 and 0.33).

The individual effect of metrical structure is significant for the cello (F (3) = 6.7, $p < 0.001$), oboe (F (3) = 8.6, $p < 0.0001$), tenor (F (3) = 8.3, $p < 0.0001$), theremin (F (3) = 5.0, $p < 0.005$), and violin (F (3) = 12.5, $p < 0.0001$). For the cello, the effect of metrical stress is such that the most heavy and intermediate heavy notes get in average larger vibrato extent than the notes that fall on a half-bar or an eighth note after beat. This may reflect a two level metrical preference that of the measure and the *tactus*. For the other instruments, the vibrato extent generally increases with the metrical stress, except for the heaviest beats. Notes that fall on positions with highest metrical stress have in average intermediate to small vibrato extent. This effect of increasing extent with increasing metrical stress may point to a communication of metrical level. The exception of the highest metrical level may reflect other considerations for the start of a measure (such as “do not start with an accent”) or may be due to conflicting considerations not taken into account in the analysis, or experimental design, since there is no counter-balancing of side-effects.

The individual effect of phrase position on vibrato extent is significant for the cello (F (2) = 6.0, $p < 0.005$), oboe (F (2) = 4.2, $p < 0.02$), and violin (F (2) = 6.3, $p < 0.005$). For the cello and oboe, the vibrato extent of notes at the start and end of the phrase is in average smaller than the vibrato extent of notes that fall in the middle of a phrase. For the violin, the effect of phrase position is notable in a smaller average vibrato extent of notes at the end of a phrase. Small extent at the start and end and larger extent in the middle may reflect a tension-relaxation strategy of a relative relaxed start, an increased tension in the middle, and resolution at the end.

The individual effect of melodic charge on vibrato extent is significant for the oboe (F (1) = 5.0, $p < 0.05$) and violin (F (1) = 44.9, $p < 0.0001$). In both cases, vibrato extent is positively correlated with melodic charge.

Effect of musical structure on mean amplitude of notes

The combined effect of metrical stress, phrase position and melodic charge as independent factors and mean amplitude per note as dependent factor is significant for all instruments (6.4 < F (6) > 27.2, $p < 0.0001$). This effect is strong for the theremin (R square = 0.60), intermediate for the oboe (R square = 0.36) and weakest for the cello, tenor and violin (R square is around 0.27).

The individual effect of metrical stress is significant for the cello (F (3) = 6.7, $p < 0.001$), oboe (F (3) = 6.7, $p < 0.001$), and violin (F (3) = 10.8, $p < 0.0001$). For the cello, the amplitude rises with *decreasing* metrical stress. For the oboe, notes at the two stronger metrical levels are performed in average louder than notes at the two weaker metrical levels. For the violin, notes with weakest metrical stress are generally loudest, notes with strongest metrical stress and at quarter-note level are in average intermediately loud, and notes at half-bar level are played in average softest.

The individual effect of phrase is significant for all instruments: cello (F (2) = 3.12, $p < 0.05$), oboe (F (2) = 6.6, $p < 0.002$), tenor (F (2) = 8.3, $p < 0.001$), theremin (F (2) = 26.0, $p < 0.0001$), and violin (F (2) = 3.6, $p < 0.05$). For the cello, the notes at the start of phrases are in average loudest, those in the middle of a phrase are in average intermediately loud and endnotes are generally softest. For the oboe and the theremin, notes at the end of a phrase are generally softer than notes at other positions. For the tenor and oboe, the opposite is case: endnotes are in average louder than other notes.

The individual effect of melodic charge is significant only for the oboe (F (1) = 39.8, $p < 0.0001$). For the oboe, the amplitude of notes rises with the melodic charge of notes.

Interrelation between amplitude, vibrato rate and vibrato extent

Vibrato rate and extent are significantly correlated negatively for the cello and tenor (r = -0.33 and –0.38 respectively). Amplitude and vibrato rate are significantly correlated for the cello and theremin (r = 0.40 and 0.48 respectively). Amplitude and vibrato extent are significantly correlated for the oboe and the violin (r = 0.39 and 0.42 respectively).

COMPARISON BETWEEN INTERVIEW AND ANALYSIS

The cellist mentioned that he stresses notes by performing them with faster vibrato. Stressed notes also suggest higher amplitude, and indeed, there exists a positive correlation between loudness and vibrato rate. The cellist also mentioned a dying away at the end of the phrase. This returns in the analysis as a general smaller vibrato extent and softer notes at the end of phrases. The statement of the cellist that no note is performed the same, with equal vibrato is not confirmed.

The oboist mentioned that she performs the first and fourth note with much vibrato, the second with less vibrato and the third note with least vibrato. This grouping of note 1 and 4 against note 2 and 3 is captured by the description of metrical stress. In the analysis, the vibrato *extent* behaves as suggested: larger average vibrato extent at notes at metrically strong positions than at metrically weak positions. Notes with heaviest metrical stress excepted: they generally get small vibrato extent. So, the oboist's mention of the long a', e' and b'' that all fall on metrical heaviest positions to have extra vibrato is contradicted. The oboist's suggestion about relaxation towards the end of the phrase returns in the analysis as a relative small vibrato extent and relative soft notes at the end of phrases. The oboist mentioned that she did not play the 8th notes with vibrato, but gave them bellies. The data analysis suggests that these bellies (which concern notes at metrically weak positions) have a relative fast vibrato rate. The intuition of the oboist that vibrato rate will increase with the loudness of notes is not confirmed. Instead, the vibrato *extent* is found to correlate with loudness. This might indicate that vibrato rate and extent are confused in the way suggested by Vennard (1967): an increase in vibrato extent is heard as an increase in vibrato rate.

Although, the tenor mentioned that he sang 'Le Cygne' with the same vibrato throughout, the analysis did show some consistent differences in mean vibrato extent between notes. Whether this is due to some control of vibrato extent by the tenor or by subtly controlling the starting and stopping of vibrato, as the tenor mentioned, is unclear; the analysis is not suited to differentiate between causes of vibrato variability. The tenor suggested that he decreased loudness towards the end of the first phrase and increased loudness towards the end of the second phrase. The analysis only tested for one general kind of treatment in respect to phrase position and confirmed the (stronger) increment of loudness at the end of the phrase. The suggestion of the tenor that vibrato is too slow for the eighth notes was not directly tested. The analysis did, however, show that the tenor sometimes used vibrato on the eighth notes, though with in average smaller vibrato extent than on longer notes.

The theremin mentioned that she changes vibrato and amplitude together. In the analysis this was only confirmed for the vibrato rate and amplitude, which did correlate positively. She also mentioned that short notes do not need much vibrato, but longer notes do. This treatment was partly confirmed in the analysis, which indicated a smaller vibrato extent for notes at a small metrical level and larger vibrato extent at notes with stronger metrical stress. It was contrasted by the high vibrato rate at note positions with weakest metrical stress, which only included eighth notes.

The violin mentioned that he performed the first phrase of 'Le Cygne' in a calm and fluent way and the second halve more intense. This could explain the effect of metrical stress in which notes at smallest metrical level were performed loudest and with highest vibrato rate. This level was only present in the second phrase. Another interpretation of the violin was that he leaned on the long a' and e' and relaxed towards the end of the (first) phrase. The analysis did not confirm this interpretation. Instead, the effect of phrase position on loudness was one of louder notes at the end of the phrase. The effect of metrical position was one of general intermediate to slow vibrato rate, extent and loudness at high metrical levels.

DISCUSSION

The most articulate answers of the musicians in the interviews concerned the production of vibrato on the instrument, the general characteristics of vibrato, such as its form and pitch, and the general function of vibrato, such as production of a warm sound, expression or legato performance. When asked, the musicians also indicated a way to use special vibrato to accentuate certain notes. Surprisingly, this special treatment often consisted of starting notes without vibrato. The musicians were explicit about their expressive intentions, such as phrasing, contrasting first and second half, and tension and relaxation of the music. They suggested related variations in vibrato.

The strongest results from the analysis of the vibrato data concerned the general considerably strong effect of musical structure on amplitude, vibrato rate and extent, the general consistency of vibrato characteristics over repetitions that is implied by this strong effect, and the limited relatedness between amplitude, vibrato rate and extent. Interestingly, all instruments had a significant relation between metrical stress and vibrato rate, while phrase position was for all instruments significantly related to amplitude. The specific direction of the effects differed between expressive aspects (e.g., amplitude, vibrato rate, and vibrato extent) and between instruments. The suggestion is that different expressive means were used for different purposes.

In general, it is clear that only few aspects that are mentioned by the musicians return in the analysis, and, vice versa, only few clear results from the analysis are mentioned by the musicians. This is not entirely surprising, since only part of expert behavior is conducted consciously and is therefore primed to be reported verbally (see Ericsson & Simon, 1980). The performances are instead a result of both automated and consciously directed processes. Nevertheless, there are two inconsistencies between analysis and interview results that are of direct importance for the study of expressive behavior. First, the musicians talk about expressive aspects of the performance in a sequential way, while the analysis tests for similar expressive treatment of notes with similar structural descriptions. In some cases, the sequential viewpoint is easily translated into a structural one. In other cases, this is less easily done and may only lead to confusion. In other words, a sequential viewpoint may be more beneficial. Second, the difference in viewpoint is especially strong if special treatment of vibrato is concerned. While expressive behavior is theoretically most often related to an intensification of vibrato rate or extent (see, e.g., Sundberg et al., 1991), the musicians actually mention to play *without* vibrato to mark a special note.

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