UNIVERSITI PUTRA MALAYSIA

THE ROLE OF VIBRATO IN THE PERCEPTION OF VIOLIN TIMBRAL QUALITY

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MICHELE LAW SOO LING

August 2002

Chairman: Dr. Minni Ang Kim Huai

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This research seeks to verify the assumption that the presence of vibrato assists listeners in "hearing" the resonance structure of a violin, hence facilitating judgments concerning violin timbral quality. Three violins of different costs and presumably different qualities were used. Listening tests were conducted to identify the perceived timbral quality of each violin. To further validate the results, body resonance curves of the violins were analyzed based upon the location and separation of two major resonance peaks. The results obtained were compared with those of previous research findings to confirm the quality of each violin. Spectrum analysis on glissando tones provided data for the plotting of the resonance curves. A pitch and vibrato detection algorithm using interpolated zero crossings was tested for its ability to accurately extract the quantifiable parameters of a vibrato, namely its rate and frequency excursion. This algorithm may be employed in resynthesis of vibrato tones.

Results of the listening test indicated that tones with vibrato were more easily discriminated in terms of quality than tones without vibrato, and the resonance curve analysis showed that there were indeed three violins of different qualities Although the ranking of the violins in the listening test and resonance curve analysis in terms of quality were not quite in agreement both were unanimous in identifying one of the violins as being perceived as the superior violin The discrepancy in ranking could be attributed to the limitations and inadequacy of equipment during the recording of tones, as well as errors and imprecision in the analysis Extraction of the vibrato parameters was successful but requires further fine tuning for more accurate results Resynthesis had been successful for fundamental frequencies, but a high-quality synthetic violin tone can only be attained if higher harmonics are taken into account

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

**PERANAN VIBRATO DALAM PERSEPSI
KUALITI BUNYI BIOLA**

Oleh

MICHELE LAW SOO LING

Ogos 2002

Pengerusi: **Dr. Minni Ang Kim Huai**

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Kajian ini bertujuan untuk membuktikan anggapan bahawa vibrato membantu pendengar "mendengar" struktur resonans biola dan oleh itu, membantu dalam penilaian kualiti biola. Tiga biola berlainan kos yang dianggap berlainan kualiti digunakan dalam kajian ini. Ujian pendengaran dilaksanakan untuk mengkaji persepsi kualiti bunyi setiap biola. Untuk mengesahkan dapatan kajian tersebut, keluk resonans setiap biola dianalisis berdasarkan kedudukan dan pengasingan dua puncak resonans utama. Hasil analisis dibandingkan dengan dapatan kajian dari pengkaji yang lain untuk mengesahkan kualiti setiap biola. Algoritma pengesan pic dan vibrato yang menggunakan interpolasi perlintasan sifar diuji untuk keberkesanannya dalam ketepatannya untuk mengekstrak parameter-parameter dalam vibrato, iaitu kadar vibrato dan sisihan frekuensi. Algoritma ini boleh digunakan dalam sintesis semula ton bervibrato.

Dapatan kajian daripada ujian pendengaran menunjukkan bahawa ton dengan vibrato membantu mengasingkan kualiti biola berbanding dengan ton tanpa vibrato Analisis keluk resonans pula menunjukkan bahawa sememangnya tiga biola tersebut berlainan kualiti Walaupun tahap kedudukan biola berdasarkan kualiti tidak setara dalam ujian pendengaran dan analisis keluk resonans, tetapi kedua-dua analisis mendapati salah satu dari tiga biola mempunyai kualiti yang tertinggi Ketidakseragaman dalam tahap kedudukan kualiti kedua-dua analisis mungkin disebabkan oleh limitasi peralatan kajian serta ralat dalam analisis Parameter-parameter vibrato berjaya diekstrak Sintesis semula dapat dilaksanakan untuk frekuensi asas, tetapi ton sintetik biola yang berkualiti tinggi hanya boleh diperolehi sekiranya harmonik-harmonik yang lebih tinggi digunakan

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"God is our refuge and strength, an ever present help in time of need "

(Psalm 46 1)

I certify that an Examination Committee met on 23rd August 2002 to conduct the final examination of Michele Law Soo Ling on her Master of Science thesis entitled "The Role of Vibrato inn the Perception of Violin Timbral Quality" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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CHAPTER ONE

INTRODUCTION

The complex resonance structures of the violin body characterize the timbre of the instrument and are peculiar to the make and model of the instrument. As the violin player rocks his finger back and forth on the fingerboard, he is essentially altering the effective length of the string, which corresponds to a frequency modulation of the pitch being played. This is vibrato. The result of the interaction between the frequency-modulated string motion and the densely spaced resonances of the violin body is the rapidly fluctuating amplitudes of the harmonics of the tone. The assumption of this research is that vibrato helps the ear "hear" the resonance structure of a violin as the harmonic amplitudes are asynchronously modulated by the walls of the spectral envelope. By this, listeners are able to discriminate between different quality violins.

In general, there are two complementing methods used in the judgment of timbral quality, namely, subjective assessment via listening tests and objective evaluation of resonance curves of frequency response curves made through physical measurements. A correspondence will then be made between the differences in the subjective and objective methods.

Violin: Structure and Acoustics

The violin is the highest pitched instrument in the string family. Four strings, tuned a fifth apart at G3 (196 Hz), D4 (293.66 Hz), A4 (440 Hz), E5 (659.3 Hz), are strung over a bridge. The strings and bridge are mounted on a hollow, wooden body containing an almost closed air space. Hutchins (1962) provides thorough physical and acoustical descriptions of the violin in her seminal work, 'The Physics of Violins'. Figure 1 shows the top and side views of the violin together with the names of various parts of the structure.

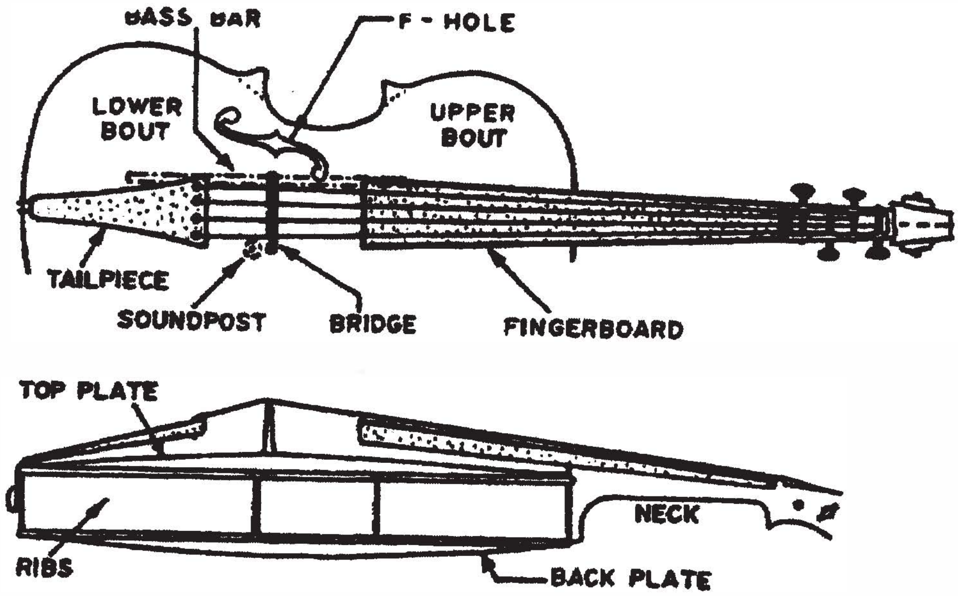

Figure 1: Parts of the Violin, Top and Side Views (from Benade, 1976)

The violin consists of three distinct sections: the sound generator, comprising the bow and string action; the resonator, or body of the violin; and the bridge, which couples the oscillating strings to the body. The primary oscillator is a stretched, flexible piece of string. As the bow is drawn across the string, sound waves are generated. However there is very little sound coming from the string alone since its surface area is too small to set a sufficient number of molecules of air in motion to initiate human audition. It is the bridge and body of the violin having larger surface areas than the strings — that transmit the string vibrations to the air.

Helmholtz observed the stick-slip motion of a violin string during bowing, from which he deduced the sawtooth wave (Figure 2a) of the string displacement, now commonly referred to as Helmholtz motion. This was accomplished using a vibration microscope. The action of a bow on the string, as with the violin, produces sawtooth-like waves. Sawtooth waves are composed of all harmonics where the amplitudes are $1/n$, and $n = 1, 2, 3, \ldots, \infty$ (Figure 2b). The timbre of a periodic complex tone is dependent on its spectral composition. However, the spectral envelope, which gives the general shape of the spectrum, is more important than the details contained within the spectrum (Hartmann, 1998).

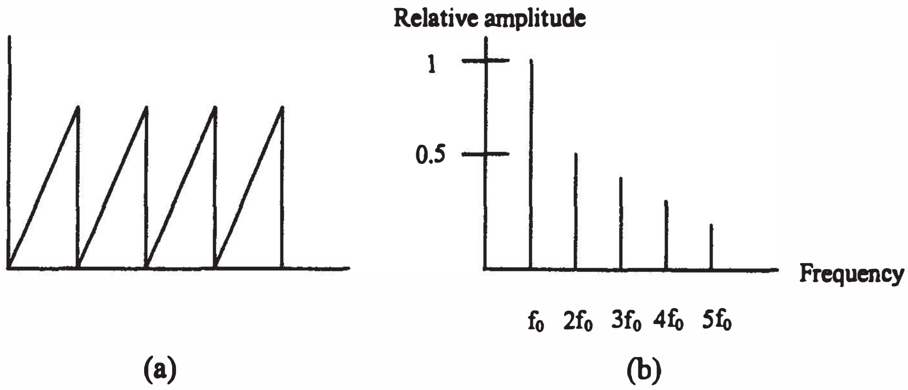

Figure 2: a) Sawtooth Wave, b) Spectrum and Harmonic Amplitudes of the Ideal Sawtooth Wave

Resonances involve the existence of natural frequencies that are easy to excite. These natural frequencies are associated with standing waves and usually include fundamental and harmonics, but sometimes also include non-harmonic overtones (Nave, 2000). The resonance properties of the violin provide information on its acoustic structure, the so-called "structural invariance" of a sound source (Michaels & Carello, 1981). Structural invariants are those properties that specify the nature of the acoustic structure of the object or group of objects participating in an event. Resonances have a noticeable effect on the timbre of musical sounds. The amplification and attenuation of certain harmonics contribute to the musical quality of the violin tone.

Vibrato

Vibrato is technically comprised of different components; it is a composite of modulations of frequency, dynamics and timbre (Desain & Honing, 1996). The present research scope focuses primarily on frequency modulations. In the case of a violin, vibrato is created by the rhythmic motion of the performer's left forearm and wrist which enables the stopped finger to rock back and forth on the fingerboard. This action by the finger changes the effective string length, which in other words, is essentially a small modulation of string length. String players usually regulate the speed of the vibrato to the range of between 5 Hz to 8 Hz, and the frequency excursion is generally about 25 cents [equivalent to one-quarter of a musical semitone].

Vibrato causes complex asynchronous amplitude modulation (AM) in the spectra of string tones as harmonics oscillate under the walls of the fixed resonances or resonant envelopes of the violin body. The amplitude of the waveform is not changing because the violin player is changing the bow pressure or velocity in synchrony with the vibrato. It must be that a prominent harmonic is moving back and forth in frequency — because of the vibrato — under the resonance having fairly steep side walls. The amplitude modulation may produce sound level changes of between 3 dB to 15 dB, resulting in a perceived loudness due to vibrato. This pulsation of intensity affects the timbre or tone colour of the instrument (Fletcher & Rossing, 1998). If vibrato affects the amplitude of the harmonics as they move up and down under the resonances, the rate at which they change should be correlated, but the amount and direction of the change in amplitude of each harmonic will not be correlated. That is, each harmonic is being affected by a different part of the resonance curve and for one, the slope may be positive while for another, it may be negative. Assuming the vibrato period is much longer than the decay time of all resonant modes, it can be assumed that the modes reach steady state at each instantaneous frequency. Hence a vibrato could effectively trace out the spectral envelope of the resonance modes of a violin.

Figure 3 illustrates the fluctuations of harmonic amplitudes during vibrato. The harmonics of a violin, indicated by solid lines, are under resonance curves as depicted diagrammatically. During a vibrato, the finger alternates between a forward rotation and a backward rotation, resulting in a shortening and lengthening of the string respectively. When the string is slightly shortened because the finger rotates a little sharp, the third harmonic ($3f_0$) is now at a position under the resonance indicated by the dotted line. Since the resonance is decreasing sharply at that frequency, the amplitude of the third harmonic will be attenuated. When the finger rotates back, lengthening the string, the amplitude of the third harmonic will increase again. So while the frequency is synchronous with all the other harmonics, the amplitudes are not because they are determined by different parts of the resonance curve of the violin. Listeners cannot "hear out" the individual harmonics, but they will be able to hear the effects as a change in tone colour. The enlarged extract of the fundamental frequency is about a quarter tone [25 cents] higher during a vibrato, and this represents the maximum range of frequency excursion of vibrato.

A vibrato sweeps up and down a small part of an octave whereas a glissando sweeps over all frequencies within its sweep. The Concise Oxford Dictionary of Music defines glissando as "passing all or part of the way from one note to another by the drawing of a finger down or up a series of adjacent notes, but the pitches passed through, instead of representing the fixed tones and semitones of a scale, are infinite in number" (Kennedy, 1980). Glissandi are similar to vibrato in that they also cause asynchronous AM.

Figure 4 shows octave sweeps of the fundamental frequency (f_0) and the second harmonic ($2f_0$). Since octaves have a frequency ratio of two to one, f_0 sweeps to 2 f_0, while 2 f_0 sweeps to 4 f_0. So the section of the resonance curve that it sweeps will shape the amplitudes of the harmonics. As the fundamental frequency sweeps the octave, so will its other harmonics, and they will pass through all the resonances. A powerful confirmation of a resonance is when the intensities of several harmonics react to the resonance in the same way and within the same frequency region.

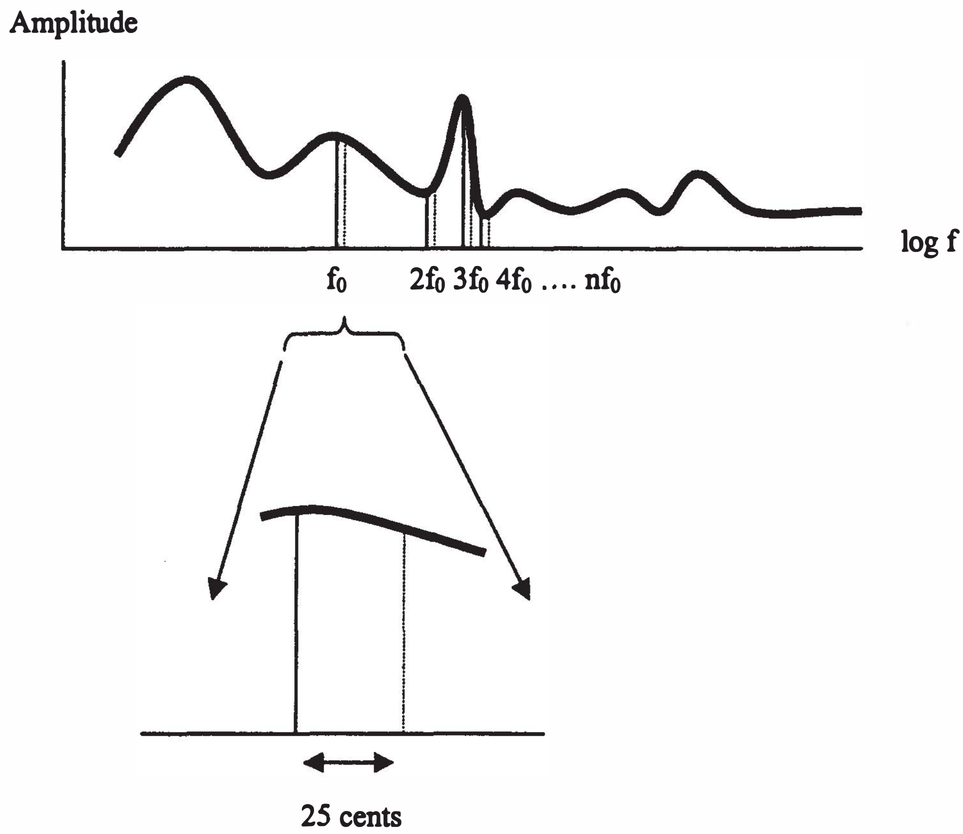

Figure 3: Frequency Modulation and Amplitude Modulation in a Vibrato