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Evaluation of the Sound Quality of a Classical Violin by Physically Measurable Acoustical Properties

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ABSTRACT

The sound quality is the key property in determining the value of a classical violin. Even though at present all classical violins look almost identical, the sound quality among them varies significantly. This paper describes the applicability of the method developed in this study to evaluate the sound quality of a classical violin using physically measurable acoustical properties. BRUEL & KJÆR PULSE multichannel sound and vibration analyser type 3160-A-042 with BRUEL & KJÆR Prepolarized Free-field ½" microphone type 4189 was used. Harmonic spectral analysis was used as the major analytical tool. Six violins were tested and compared experimentally. Furthermore experts' judgements of the six violins were taken by violin experts and compared with the experimental results. The experiments were designed under two main categories to determine the time independent and time varying acoustical properties of a violin. The contribution level of each harmonic to the total complex sound was calculated by assuming those harmonics as separate, independent sound sources which contribute to the total sound. A set of objective sound quality parameters was assigned in each experiment and those parameters were quantified by using the calculated contribution levels. A marks allocation system was introduced to quantify the assigned sound quality parameters which are contributed positively or negatively to the sound quality of each violin. The quantified sound quality properties of each violin by the marks allocation system are reasonably agreed with the experts' judgements. Therefore it is possible to evaluate the sound quality of a classical violin using the method developed in this study.

1. INTRODUCTION

Most violinists and violinmakers are predominantly interested about the sound quality of a classical violin. The art of violin making has a great history. Cremona violins were occupied a remarkable unique place in violin history. The most famous violin makers, Antonio Stradivari (1644c-1737), Nicolo Amati (1596–1684), Andrea Guarneri (1624c–1698) raised sound quality of a classical violin of its ultimate level of perfection [1, 2].

After a violin is finished in its making process, the very important and critical thing is the evaluation of its sound quality and also gives a prize to it. Usually it is done by a violin expert. The evaluation of sound quality done by violin experts is a totally subjective parameter (It is fully related to the perception of sound). It must be emphasized that no scientific method can replace the trained ear which is the ultimate arbiter in violin playing and making. But experts' judgments are depended on numerous factors; for examples, on some favours, tiredness, current mood, etc. So additional to the experts' judgments, a method of measuring or quantifying the sound quality of a violin, using physically measurable acoustical properties (Objective parameters), is needed and it is very important for both violinists and violin makers to make a best evaluation of sound quality of a violin.

2. EXPERIMENTAL

2.1 Violins

Six violins were used in experiments. They were labelled as VR, V1, V2, V3, V4 and V5. The violin VR is the best one and it was considered as the reference violin in this study. It is the violin of master musician and concert violinist Mrs. Thushani Jayawardane, Leader of the Symphony Orchestra of Sri Lanka. It is a special old master piece which was made by Nicolo Amati in Cremona, in 1660. The violin V1 is a handmade copy of Stradivarius model and it was made in Germany, in 2007. The violin V5 is a handmade copy of Guarnerius model and it was made in Cremona. Other three violins V2, V3 and V4 are normal violins which were made in China and they are not typical hand-made violins.

2.2 The Experimental Arrangement

Experiments were performed by using two violinists. The same bow and the same type of strings were used for all violins for the same condition. All the sound measurements and analysis were carried out by using the BRUEL & KJÆR PULSE multichannel sound and vibration analyser type 3160-A-042 with BRUEL & KJÆR Prepolarized Free-field ½" microphone type 4189 and PULSE LabShop software version 19.0.0.128. The sound measurements were taken in the near field condition (at about 1m distance from the violin player). Sound measurements were carried out in a large room having reverberation time less than 0.7sec. Dimensions of the room were nearly 13m length, 6m width, and 3m height. The microphone and player were placed at the centre of the room.

2.3 Experiments

In this study experiments were designed under two main categories to determine the time independent and time varying acoustical properties of a violin. Single notes and Dual string experiments were designed to determine the time independent properties. Vibrato experiment was designed to determine the time varying properties.

2.3.1 Single Notes Experiment

The main objective of this experiment was, to determine the characteristics of the harmonic spectrums of selected eight notes of each violin. Sound measurements of four open strings (G3, D4, A4 and E5) and four touch notes (A3, B4, F#5 and B5) were taken. Touch notes were played without vibrato. The eight notes were selected as to cover low, middle and high frequency ranges.

2.3.2 Open Dual String Experiment

The main objective of this experiment was to study the level of consonance by determine the contribution levels of coincident harmonics of a harmonic spectrum of a 5^{th} harmony of each violin. In this experiment, sound measurements of three pairs of open dual string; A4,E5; D4,A4; G3,D4 were taken.

2.3.3 Vibrato Experiment

Vibrato is a very important technique used by violinists. The main objective of this experiment was to study the quick response of the sound box of a violin to very rapidly changing frequencies in a narrow frequency range, nearly 10Hz. In this experiment sound measurements of two vibrato notes (A4 and A3) are taken. The two notes are selected in low and middle frequency ranges.

3. RESULTS AND DISCUSSION

A set of objective sound quality parameters was assigned in each experiment by analysing the experimental data of sound measurements with respect to the sound measurements of the reference violin (VR) and known sound theories related to violin sound quality and music [3, 4]. Furthermore, the sound quality of each violin was quantified by assigning marks for those sound quality parameters.

3.1 Single Notes and Dual String Experiments

In these experiments, FFT narrow-band frequency analysis was used to determine the exact frequencies of harmonics and their corresponding individual sound pressure levels in decibels. Overall and time-signal analysis were used to determine the contribution levels of harmonics to the total complex wave form. In the analysis, each harmonic of the harmonic spectrum was assumed as a separate sound source which has a contribution to the total complex sound. Then following equation was used to calculate the overall sound pressure level, L_c and contribution levels of the harmonics. Then L_c value was compared with the measured overall sound pressure level, L_m. L_n is the individual sound pressure level of nth harmonic.

$$L_c = 10log_{10}\left[\sum_n 10^{L_n/10}\right]; n = 1,2,3, \ldots (1)$$

Experimentally obtained harmonic spectrums, waveforms, calculated contribution levels and corresponding assigned marks of A4 note (with 440Hz fundamental frequency) of only VR and V4 violins are summarized in Figure 1, Figure 2, Table 1 and Table 2.

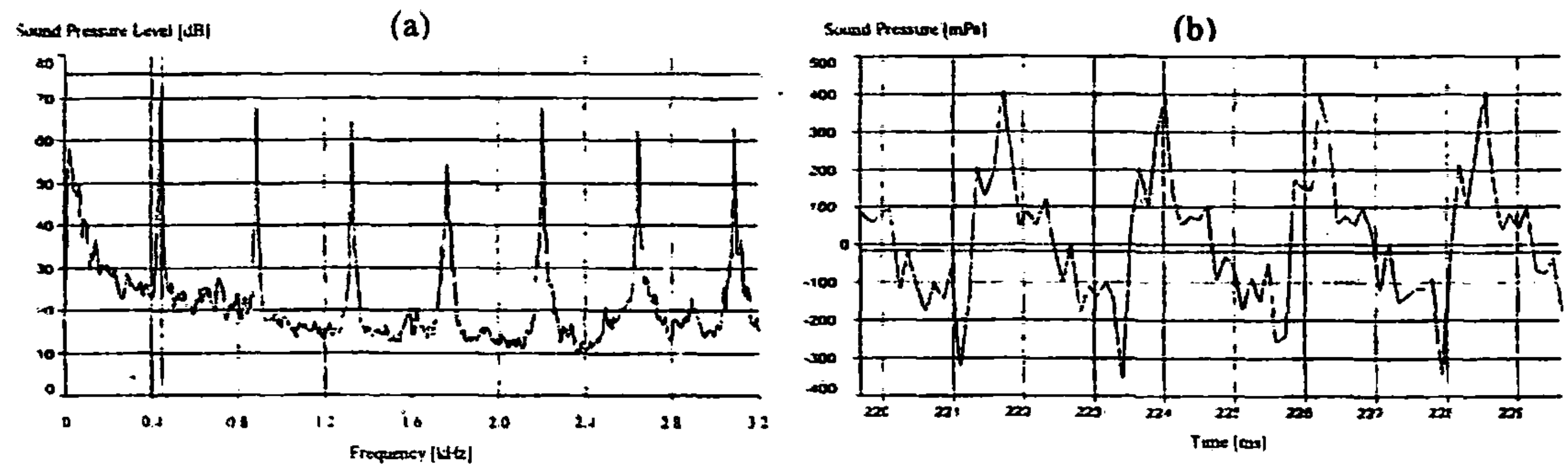

Figure 1 – (a) Harmonic spectrum and (b) waveform of A4 note of VR violin.

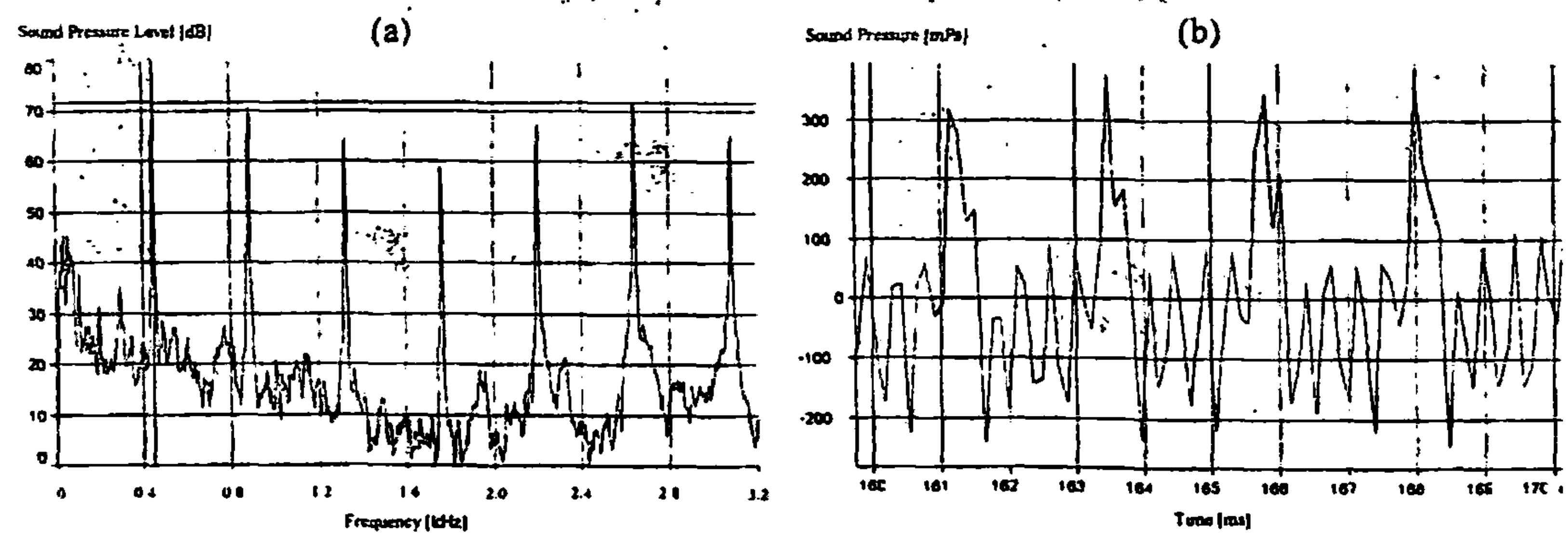

Figure 2 – (a) Harmonic spectrum and (b) waveform of A4 note of V4 violin

Table 1 – Calculated contribution levels of harmonics of A4 note of VR and V4 violins

Violin-VR			Violin-V4		
$L_m = 78.9dB$	$L_c = 77.3dB$		$L_m = 77.3dB$	$L_c = 77.3dB$	
Harmonic Number Configuration	L_c(dB)	Contribution Level ΔL(dB)	Harmonic Number Configuration	L_c(dB)	Contribution Level ΔL(dB)
(1)	75.5	-	(1)	71.6	-
(1)+2	76.2	0.7	(1)+6	74.4	2.8
(1+2)+5	76.7	0.5	(1+6)+2	75.9	1.5
(1+2+5)+3	76.9	0.2	(1+2+6)+3	76.4	0.5
(1+2+3+5)+4	76.9	0.0	(1+2+3+6)+5	76.9	0.5
(1+2+3+4+5)+6	77.1	0.1	(1+2+3+5+6)+7	77.2	0.3
(1+2+3+4+5+6)+7	77.3	0.2	(1+2+3+5+6+7)+4	77.3	0.1

Table 2 – Marks of A4 note of VR and V4 violins

No.	Sound Quality Parameter	VR	V4
1	Number of prominent low numbered harmonics **6 for 3 harmonics; 5 for 2 harmonics**	6	6
2	Contribution level of low numbered harmonics **2 for each harmonic with $\Delta L \geq 1$; 1 for each harmonic with $\Delta L \geq 0.5$**	2	3
3	Contribution level of 6th or 7th harmonics **0 for $0 \leq \Delta L \leq 0.2$; -2 for $0.3 \leq \Delta L < 0.5$; -4 for $\Delta L \geq 0.5$; -5 for both 6th and 7th**	0	-5
	Total	8	4

3.2 Vibrato Experiment

Data analysis of this experiment was carried out using multi-buffer and overall analysis. Multi-buffer analysis (Time varying frequency analysis) was used to observe the time dependent rapid frequency change. In a vibrato note, the frequency is rapidly changed around a centre frequency in a very narrow frequency band. In the case of A4 vibrato note the centre frequency is 440Hz and the frequency band is nearly 10Hz. In this analysis, Y and X axes are represented time and frequency respectively. The sound pressure levels are represented by colour contours. Experimentally obtained characteristic graphs, corresponding assigned marks of A4 vibrato note of only VR and V4 violins are summarized in Figure 3 and Table 3.

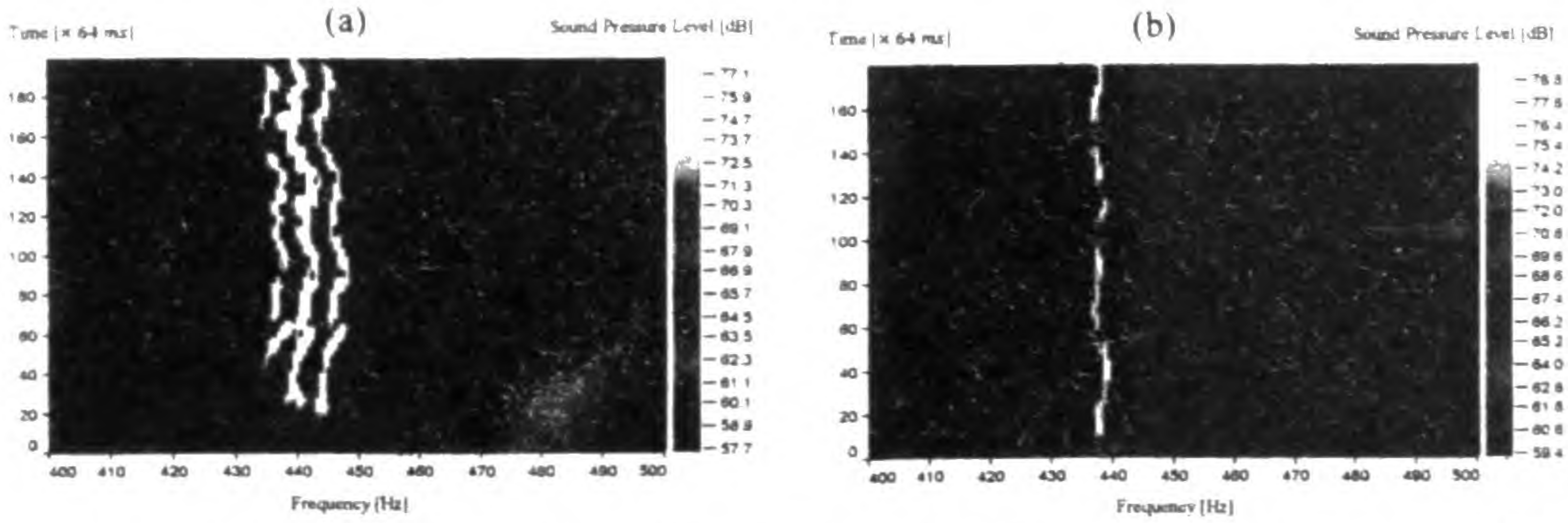

Figure 3 – Characteristic multi-buffer graphs of A4 vibrato note of (a) VR and (b) V4 violins

Especially the set of results of this experiment was a good indicator of sustainability of the sound. The continuity and the contribution level of the three frequency lines are indicated high sustainable sound because it implies that frequency is changed with time without making discontinuities in sound.

Table 3 – Marks of A4 vibrato note of VR and V4 violins

No.	Sound Quality Parameter	VR	V4
1	Continuity of three contour lines **5 for High; 3 for Medium; 1 for Low**	5	1
2	Contribution level of lower and upper bound frequency lines **5 for High; 3 for Medium; 1 for Low**	5	1
	Total	10	2

All the sound measurements of the six violins of these three experiments were analysed in a similar method described above. The total assigned marks of all violins in each experiment are summarized as follows.

Table 4 – Total marks of Single notes experiment

			Marks					
Frequency Range	Note	Fundamental Frequency (Hz)	VR	V1	V5	V2	V3	V4
Low	G3	196	9	6	6	9	9	8
	A3	224	9	6	8	5	9	5
Medium	D4	292	10	9	9	10	10	8
	A4	440	8	10	7	8	6	4
	B4	496	9	8	9	7	5	10
High	E5	656	10	7	9	4	7	8
	F#5	744	9	8	9	10	8	6
	B5	992	8	10	10	8	10	8
	Total Marks		72	64	67	61	64	57
	%		90.0	80.0	83.8	76.2	80.0	71.2

Table 5 – Total minus marks of Single notes experiment

			Minus Marks					
Frequency Range	Note	Fundamental Frequency (Hz)	VR	V1	V5	V2	V3	V4
Low	G3	196	0	0	0	0	0	0
	A3	224	0	-2	0	-2	0	-4
Medium	D4	292	0	0	0	0	0	0
	A4	440	0	0	0	0	-2	-5
	B4	496	0	0	0	-2	-4	0
High	E5	656	0	-2	0	-5	-2	0
	F#5	744	0	-2	0	0	-2	0
	B5	992	0	0	0	0	0	0
	Total Marks		0	-6	0	-9	-10	-9

Table 6 – Total marks of Dual string experiment

		Total Marks					
Note	Fundamental Frequency (Hz)	VR	V1	V5	V2	V3	V4
G3, D4	196, 292	8	8	4	8	5	4
D4, A4	292, 440	8	10	8	8	0	8
A4, E5	440, 656	8	10	3	6	3	8
Total Marks		24	28	15	22	8	20
%		80.0	93.3	50.0	73.3	26.7	66.7

Table 7 – Total marks of Vibrato experiment

		Marks					
Note	Fundamental Frequency (Hz)	VR	V1	V5	V2	V3	V4
A3	224	10	8	2	2	4	4
A4	440	10	8	4	6	6	2
Total Marks		20	16	6	8	10	6
%		100	80	30	40	50	30

3.3 Overall Estimation

Overall estimation, T of violin sound quality is done by a weightage equation which included the results of all three experiments (where S, V and D are the total marks of single notes, vibrato and open dual string experiments respectively). The highest weightage (0.6) is given for single notes experiment since it covers a wide range of frequency (196Hz-992Hz). The second highest weightage (0.3) is given for vibrato experiment since it is a very important technique in violin playing and also a good indicator to evaluate the sustainability of a violin. That equation is;

$$T = (0.6\times S) + (0.3\times V) + (0.1\times D) \quad \ldots\ldots (2)$$

Table 8 – Overall marks of six violins

	Marks (%)					
Experiment	VR	V1	V5	V2	V3	V4
Single Notes	90.0	80.0	83.8	76.2	80.0	71.2
Open Dual String	80.0	93.3	50.0	73.3	26.7	66.7
Vibrato	100.0	80.0	30.0	40.0	50.0	30.0
Overall	92.0	81.3	64.3	65.0	65.7	58.4

The VR violin is obtained the highest overall marks (over 90). It is important to notice that the marks obtained by this violin are high (>80) in all three experiments. These results imply that high performance of both time independent and time varying acoustical properties of this violin. The harmonic configuration of each tone is largely confined to a few low numbered harmonics (1^{st} to 5^{th}) with high contribution levels and it confirms the special characteristic of famous Italian old classic violins [1, 3, 4]. The contribution levels of higher numbered harmonics, 6^{th} and 7^{th} are minimal and it confirms the free of problem with delicate shrillness and harshness sound [3, 4]. Especially in the vibrato experiment this violin exhibits the highest performance and that reveals the high response of the sound box to rapidly changing frequencies which causes to a high sustainable sound.

It is very important to notice that, the V5 violin is obtained medium overall marks (around 65) even though it is a handmade copy of Guarnerius model. This is an old violin but had been subjected to a major repair recently and it may be the reason for this low performance. The contribution levels of 6^{th} and 7^{th} harmonics are minimal but the contribution levels of low numbered harmonics are also relatively low (especially in low frequencies) with respect to the reference violin and it reveals the tonal characteristics of the sound (less complexity in wave forms) of this violin with no shrillness and harshness sound. Especially in the vibrato experiment this violin exhibits low performance and it reveals the low response of the sound box to rapidly changing frequencies. It implies the low sustainability of this violin sound.

The V4 violin is obtained the lowest overall marks (below 60). The contribution levels of low numbered harmonics are relatively high but the contribution levels of 6th and 7th harmonics also very high mostly in law and medium frequency regions. It implies this violin has the problem of shrillness and harshness sound mostly in low and medium frequency regions. Especially this violin exhibits very low performance in vibrato experiment even though it shows medium performance in other two experiments. It implies the low sustainability of the violin sound and unbalanced nature of the sound quality.

3.4 Experts' Judgments

Judgements of each violin were taken by two independently working violin experts. During this process the musicians knew only the number assigned to the violin. They judged according to the four main categories: Timbre of violin sound. Sound quality balance through wide pitch range (low, mid and high). Loudness of sound and Sustainability of sound. The comparison of the experts' judgements and the results of the marks allocation system is shown in Table 9.

Table 9 – Comparison of the experts' judgements and results of the marks allocation system

Violin	Experts' Judgements	Results of the Model
VR	It has a smooth, warm, beautiful, vibrant, rich tone colour.	❖ Over 90 overall marks ❖ 90 marks for Single notes experiment ❖ Zero minus marks
	It has a well-balanced same sound quality in all pitch ranges.	❖ High individual marks(≥ 8) for each note in Single notes experiment ❖ High marks(> 80) for all three experiment
	Volume is high and it has a high sustainable tone.	❖ 100 marks for Vibrato experiment
V1	It has a strong, rich, dark tone colour.	❖ Over 80 overall marks ❖ Over 90 marks for Dual string Experiment
	But it has a little bit harsh sound mostly in high pitch region.	❖ 4 minus marks for high frequency region($> 650Hz$)
	It has high sustainability and volume.	❖ 80 marks for Vibrato experiment
V5	It has a very soft beautiful tone, more like viola sound.	❖ Over 60 overall marks ❖ Zero minus marks
	It has the same sound quality in all four strings.	❖ High individual marks(≥ 7) for 7 notes in Single notes experiment
	But the volume and sustainability is low. The sound is mute very quickly.	❖ 30 marks for Vibrato experiment
V2	It has a smooth tone. But the tone colour changes in different pitch ranges.	❖ Over 65 overall marks ❖ Individual marks of notes in Single notes experiment are varied from 10 to 4
	It has a harsh sound mostly in high pitch region.	❖ 7 minus marks for mid and high frequency region($660Hz > f > 490Hz$)
	It has high volume but sustainability is low.	❖ 40 marks for Vibrato experiment
V3	It has a smooth and strong tone. But the tone colour changes in different pitch ranges.	❖ Over 65 overall marks ❖ Individual marks of notes in Single notes experiment are varied from 10 to 5
	It has a harsh sound mostly in mid and high pitch region.	❖ 10 minus marks for mid and high frequency region($745Hz > f > 440Hz$)
	It has low volume and medium sustainability.	❖ 50 marks for Vibrato experiment

V4	It has a very rough, harsh tone, metallic sound.	❖ Below 60 overall marks ❖ 9 minus marks for low and mid frequency region($440Hz > f > 220Hz$)
	Tone colour changes in different pitch ranges.	❖ Individual marks of notes in Single notes experiment are varied from 10 to 4
	It has high volume and medium sustainability.	❖ 30 marks for Vibrato experiment

4. CONCLUSION

The experiments presented in this paper were designed to develop a method to evaluate the sound quality of a classical violin using physically measurable acoustical properties. The analytical techniques used in this study were suited to determine both time independent and time varying acoustical properties of a violin. The results reveal that single notes and dual string experiments are suitable to determine the characteristics of time independent acoustical properties and vibrato experiment is suitable to determine the characteristics of time varying acoustical properties. The exact frequencies and individual sound pressure levels of harmonics of a harmonic spectrum could be determine by FFT narrow-band frequency analysis. The contribution level of each harmonic to the total complex sound could be calculated by assuming those harmonics as separate sound sources which contribute to the total sound. The verification of those calculated contribution levels could be determined by time-signal and overall analysis. It was discovered that the minimum contribution level of a harmonic is 0.3dB which affect to make a minimum change to the total waveform pattern. A set of objective sound quality parameters was assigned in each experiment and those parameters could be quantified by using the calculated contribution levels. Using the marks allocation system which was introduced in this study, it was able to quantify the assigned sound quality parameters which are contributed positively or negatively to the sound quality of each violin. The comparison which is given in Table 9 confirms that the quantified sound quality properties of each violin by the marks allocation system are reasonably agreed with the experts' judgements. For this reason, it is fair to assert that the method developed in this study fulfil its main function, i.e. the ability to evaluate the sound quality of a classical violin using physically measurable acoustical properties.

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