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SOUND AND VIBRATION RESPONSE OF PLAYING VIOLA BY MEANS OF NORMAL AND SCORDATURA TUNING METHODS

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The Austrian classical music composer Mozart instructed the viola to use a special tuning method, Scordatura, in his prestigious. The Scordatura (S) tuning is to alter the tuning of a string to a semi-tone higher than the standard or normal (N) tuning such that the playing sound of viola can be brighter with larger loudness. To our best knowledge, there is no scientific evidence to show this brighter and louder effect but only the subjective evaluation by musicians. This work is to discuss the playing sound of viola by using the S-tuning in comparison to the N-tuning as well as the top plate vibration during playing. The four strings of viola are played individually and recorded their sound that are analyzed to examine the spectrum and spectrogram for objective evaluation. In subjective evaluation, the professional musician's hearing on both tuning method is discussed. The music from Mozart is also played for the two tuning methods, respectively. The objective evaluation via time wave form, sound spectrum and sound spectrogram is presented to show the difference of playing sound from the two tuning methods and characterize the brightness and loudness. The correlation between the playing sound and top-plate vibration response is also examined. A simple ping test on the viola top plate is then performed to measure the tri-axial acceleration and obtain structural natural frequencies and corresponding vibration spectrum. Results show the viola in the S-tuning reveals higher structural resonances than that in the N-tuning. The physical mechanism of sound and vibration in affecting the playing sound of viola by the normal and Scordatura tuning can be further calibrated.
Keywords: viola, Scordatura tuning, standard (normal) tuning, objective evaluation

1. Introduction

In the string family, the viola has been overshadowed by its smaller and larger "superior" siblings: the violin and the cello. Lacking brilliant sound of the violin and strong resonance of the cello disadvantage the viola for being a solo instrument. To change the situation, several late 18th century composers such as Johann Andreas Amon, Georg Druschetsky, and Johann Baptist Vanhal employed *transcription scordatura*, a tuning technique "in which all four strings were raised either a tone or a semi-tone for greater brilliance, carrying power and facility of execution" [1]. Wolfgang Amadeus Mozart's *Sinfonia Concertante in E-flat major for Violin, Viola and Orchestra, K. 364* (1779-80) is the most significant among these viola scordatura pieces. With scordatura, the solo violist tuned his/her instrument all four strings a semi-tone higher to brighten the sound, results in an easier key of D major that utilizes more open strings. The solo violin and the orchestra remain in the standard tuning and play in the key of E-flat major, a key that restricts open fingerings and affects the overall resonance on the string instruments. Thus, Mozart provided the solo viola great advantages over the solo violin and the entire orchestra in this piece.

Despite the advantages that the solo viola could benefit from the scordatura, this historical practice in Mozart's *Sinfonia Concertante* is often neglected in today's music scene. The majority of music publishers provide scores only in the standard tuning. The modern violists therefore are unaware of the scordatura history in this piece and simply do not have the options to execute it. British scholar Donald Francis Tovey's considered scordatura as a redundant act: "The motive for the device [scordatura] in this particular case is that if the viola in question is not a very good instrument it becomes more brilliant by having its pitch raised. But a fine instrument loses more than it gains by the process; and to insist on it is a mistaken piety" [2]. In a recent concert survey, audiences noticed the advantages and stated that "the scordatura gives clearer singing tones which blends more easily with the solo violin" while others provided their subjective opinions and thought "the scordatura makes the viola match the solo violin's timbre much better than in standard turning" [3].

From the engineering point of view, musical instrument playing sound account for many acoustical properties, such as pitch, loudness and harmonic contents [4-6]. Researchers used timbre or tone color to describe the playing sound quality. Saitis et al. [7] investigated how musicians conceptualize the connection of sound quality and performers and discussed the relation between perceptual evaluations and physical description.

Researchers also tried verbal attributes to define the dynamic behaviour and perceived quality for violin. Dünnwald [8] proposed objective quality parameters from sound spectrum response of violin. Hutchins [9] examined the violin tone related to frequency range of projection. Schleske [10] used such as soft/harsh and dark/bright to categorize tonal attributes. Lukasik [11] proposed the spectral centroid to correlate bright/dark. Saitis et al. [12] observed that spectral centroid is related to sound richness. Hermes et al. [13] showed the timbre clarity for string instrument sound can be classified by harmonic centroid.

This study presents objective evaluation via time waveform, sound spectrum and sound spectrogram to show the difference of playing sound from the two tuning methods, i.e. standard (normal) and Scordatura. These objective evaluation helps characterize the brightness and loudness brought by scordatura which described in subjective evaluation in literature review.

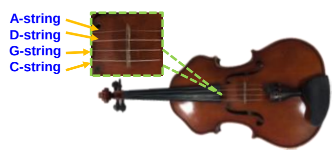
2. Experimental setup for sound and vibration measurement

Scordatura is a tuning method for a stringed instrument different from the standard or normal tuning. In this work, the viola with four strings in standard or normal tuning (N-tuning) are tuned at C, G, D and A. The scordatura tuning (S-tuning) alters the tuning of a string to a half tone higher than the N-tuning such that the playing sound of viola can be possibly brighter with larger loudness.

This work is to investigate the difference between the S-tuning and N-tuning for viola. Two tests are arranged, i.e. the In-playing test and Ping-test, for both tuning methods on the same viola. Figure 1(a) shows the photo of viola with four strings, i.e. A, D, G, and C strings. Figure 2 shows the test plan for In-playing tests. The first test is to play designated notes on each string by pressing at different locations as shown in Figure 1(b). There are seven notes for each string to be tested. The other In-playing test is to play the first theme from the first movement of Mozart's *Sinfonia Concertante* K.364. Figure 2 shows the notation for both standard/normal tuning and Scordatura tuning.

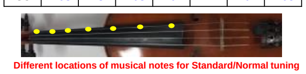
Figure 3 shows the experimental setup for sound and vibration measurement during the In-playing tests. The player is one of the authors, Dr. Chiang, the principal viola of a professional orchestra who can play viola steadily. The measured data is assumed stable and reliable for further study. The microphone is placed about 30cm away from the viola during test, while a tri-axial accelerometer is attached on the top-plate near the middle of top side to measure three directional accelerations, denoted as Ax, Ay and Az in the followings. The sensors are connected to the four-channel data acquisition (DAQ) device, NI-9234, in corporate with Sound and Vibration Measurement (SVM) software [14] to collect the playing sound and top-plate vibration. The time waveforms can be captured and stored for further spectral analysis. The effective frequency range is 20 kHz with 1.56Hz frequency resolution. The SM software [15] is also used to do spectral analysis and obtain spectrogram for both sound and vibration.

As known, the S-tuning is to raise the pitch frequency of each string by a semi-tone than the N-tuning, and therefore the string tension increases and may result in more tension in the top-plate. The more pre-stressed on the viola may incur higher vibration modes. This work performs the Ping-test, using finger to tap the top-plate, while the tapped vibration and sound are collected simultaneously. The Ping-test is designed to observe the possible change of structural resonances for higher tension force on the top-plate due to the S-tuning. The other intention is to investigate the correlation between the viola sound and vibration for both In-playing and Ping-test conditions as well as the variation and difference between the S-tuning and N-tuning.



(a) Photo of viola

A4	Bb4	D5	F5	Bb5	D6	F6	Bb6
D4	Eb4	G3	Bb4	Eb5	G5	Bb5	Eb6
G3	Ab3	C4	Eb4	Ab4	C5	Eb5	Ab5
C3	Db3	F3	Ab3	Db4	F4	Ab4	Db5



(b) Different notes on the string for testing

Figure 1: The four strings of viola.

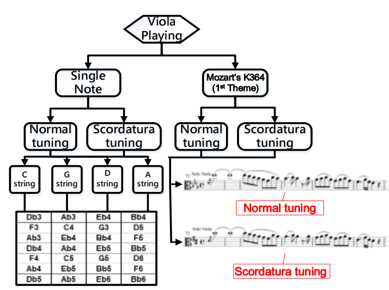


Figure 2: Sound and vibration measurement for different tuning methods.

Figure 3: Experimental setup for sound and vibration measurement.

3. Comparison of sound and vibration response for playing viola

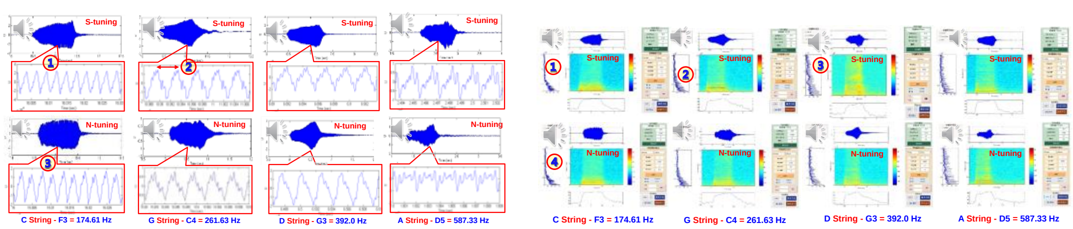
The experiments include both the In-playing and Ping-test, and both the playing sound and top-plate vibration of viola are monitored. This section will investigate the difference between the S- and N-tuning, in terms of time waveform, spectrum and spectrogram.

3.1 Sound response for playing same note by S- and N-tuning

The first question regarding different tuning methods, i.e. the S- and N-tuning, is what the difference is when playing the same note. Figure 4(a) shows the time waveforms for playing same note by two tuning methods. For example, the left column in Figure 4(a) shows sound response for playing the note F3 (174.61 Hz) on viola's C string. The top figure is by the S-tuning and the bottom is by the N-tuning. Several observations as numbered on the plot are discussed as follows. (1) The enlarged time waveforms clearly show the periodic signals that are typical for string instruments and may produce harmonics in spectrum. (2) The repeat period can be identified as the inverse of fundamental frequency. (3) It is interesting to note that the time waveforms reveal slight differences for the same note that was played by different tuning methods.

Figure 4(b) show the same signals as Figure 4(a) for spectrogram analysis. Several observations as numbered on the plot are discussed as follows. (1) The lower pitch such as Figure 5(a) for C-string, F3=174.61 Hz only incurs up to 7000 Hz sound spectrum. (2) One can clearly observe the harmonics in sound spectrum for the periodic effect in time waveforms. (3) Other than the harmonics, there are the evidences of resonance effects with peak response in spectrum. (4) One cannot really distinguish the difference between the S- and N-tuning in the spectrogram analysis.

For better understanding the difference between the S- and N-tuning, Figure 5 shows the sound spectrum comparison for those in Figure 4. The observations are as follows. (1) The pitch frequency and its harmonics reveal as expected for all of playing sound. (2) In general, the first fundamental frequency, i.e. the first peak frequency or the pitch frequency, has the highest peak response. For C-string, F3=174.61Hz in Figure 5(a), the second harmonic has the highest peak response that may be due to resonance induced from the effect of structural natural frequency. (3) From Figure 5(c), that the peak frequencies of higher harmonics for the N- and S-tuning are not coincident with each other indicate there is not exact the same fundamental pitch frequency. (4) The main point to examine is how different tuning will affect the playing sound. Unfortunately, the spectrum from the N-tuning or S-tuning may be higher or lower. There is no consistent phenomenon. The mystery whether the S-tuning really resulting in brighter or louder playing sound than the N-tuning is not solved yet at the stage.



(a) Time waveforms (b) Spectrogram

Figure 4: Playing sound for different tuning methods with the same note.

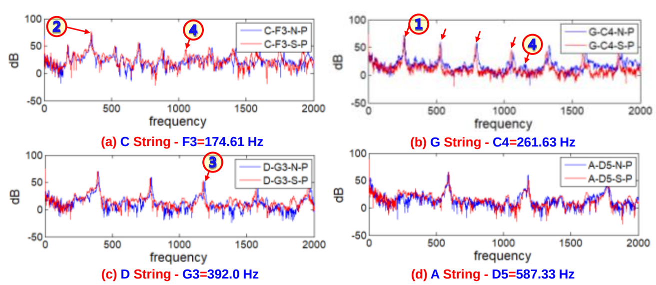


Figure 5: Playing sound for different tuning methods with the same note: Sound Spectrum.

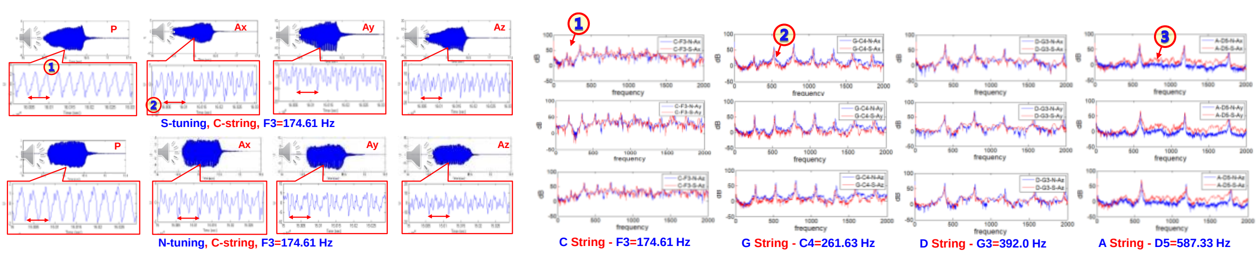
3.2 Playing sound and vibration response for playing same note by S- and N-tuning

For further investigation on the mystery of S-tuning effect, the top-plate vibration response are examined. Figure 6(a) shows the time waveforms from In-playing test on C-string with the same note F3=174.61 Hz for both S- and N-tuning, respectively. The notations P and Ax, Ay, Az on the plot denotes the sound pressure response and the three directional acceleration response on the top-plate, respectively. (1) For the playing sound and top-plate vibration, in close examination of enlarged time waveforms, the

Ax response for S- and N-tuning are quite the same, while P, Ay and Az are only similar. (2) The period corresponding to the pitch frequency F3=174.61 Hz is depicted on each plot. It is noted that in Figure 5 for F3=174.61 Hz, the second harmonic has the highest peak response, and here the P response actually reveals the two repeated cycles in one period. Also, note that the vibration signals can be converted to wave files, and one can clearly identify the same pitch sound as well. This indicates that the top-plate structure vibrates due to the string vibration excitation dominantly.

In Figure 5, the difference of playing sound between the S- and N-tuning was examined. Figure 6(b) shows the corresponding top-plate vibration response comparison between the S- and N-tuning. In the plots, red lines denote the S-tuning and blue lines indicate the N-tuning. The notations in Figure 6(b), for examples C-F3-N-Ax and C-F3-S-Ax, denote C-string, note F3, N- and S-tuning, respectively, and Ax for x-direction response. (1) The peak response in acceleration spectrum are very alike between the S- and N-tuning. (2) In Figure 6(b) for G-string C4=261.63 Hz, the blue spectrum for the N-tuning are generally with higher response than the red ones for the S-tuning. (3) In Figure 6(b) for A-string D5=587.33 Hz, the red spectrum are generally higher than the blue ones. This phenomenon is about the same as that in Figure 5. The playing and top-plate vibration reveal similar effect for both S- and N-tuning. Again, there is no consistent phenomenon for which tuning may result in higher response. .

The next question is how the correlation between the playing sound and top-plate vibration. Figure 7 examine the spectrum of playing sound and top-plate vibration for the A-string played with note D5=587.33Hz for S-tuning. In the plots, the blue line is for playing sound, while the red line is the directional vibration spectrum. (1) All directional vibration reveal harmonics the same as the playing sound. (2) Even the small peak response in playing sound relatively lower than the harmonics also coincides with the peaks in acceleration spectrum. This indicates structural resonances do affect the playing sound. (3) There is the evidence of structural resonances from vibration spectrum. Some resonances will contribute to the playing sound and some will not. The next interesting thing to know is how the viola resonates differently between the S- and N-tuning.



(a) Time waveforms (b) Ax, Ay, Az Spectrum

Figure 6: Playing Sound and top-plate vibration for different tuning methods with the same note.

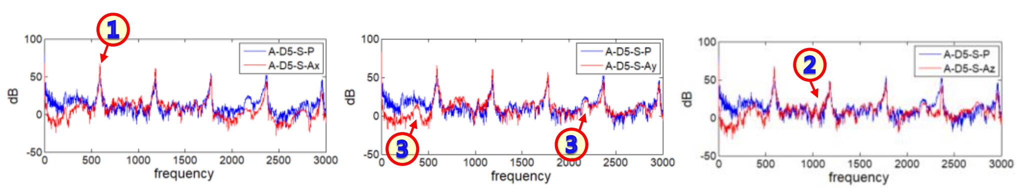


Figure 7: Comparison of Spectrum between Playing Sound and top-plate vibration for S-tuning.

3.3 Correlation between In-playing and Ping-test

As mentioned in Section 2, the Ping-test on the top-plate of viola is also performed in order to examine the possible viola structural resonances via finger's tapping force excitation. Figure 8 shows the resultant vibration spectrum in Ax, Ay and Az directions. The red line is for the S-tuning, and the blue is for the N-tuning. (1) The acceleration spectrum are much alike each other in term of spectrum distribution. (2)

The peak frequencies are slightly different between the S- and N-tuning. Generally speaking, the resonance frequencies are slightly higher in S-tuning than in N-tuning. This can be the cause that the S-tuning has higher tension force in the string and affecting the structural resonances. (3) The level of vibration is generally higher in S-tuning than in N-tuning. However, the Ping-test is not a precise test. More precision measurement is required to calibrate the detail differences between the S- and N-tuning. Nevertheless, the viola structural natural frequencies do change with no doubt.

In Figure 7, we have examined the spectrum of playing sound and top-plate vibration that are strongly correlated. Figure 9 compares the top-plate vibration response between the Ping-test and In-playing for A-string with D5=587.33 Hz between the S- and N-tuning. In the plots, the blue line is for the Ping-test, and the red line is for the In-playing test. (1) For In-playing test, the acceleration spectrum appears harmonics related to the pitch frequency. (2) The peaks in spectrum from Ping-test can be realized as the structural natural frequencies. The vibration response during In-playing test also appears those resonance peaks, although the levels are not high in comparison to those of harmonics. However, if the playing note is coincident to the top-plate resonances, such as observed in Figure 5(a), the playing sound in the structural resonance frequency will be amplified due to resonance excitation effect. This also explains why the non-consistence phenomenon either in S-tuning or in N-tuning. (3) Although the tapping force in Ping-test is quite small, the blue lines, i.e. vibration levels in Ping-test, are generally higher than that in In-playing test. However, it is noted that vibration levels at the pitch frequency and related harmonics in acceleration spectrum are much higher than those in Ping-test. This indicate that the string vibration dominantly induces the top-plate response.

As mentioned the non-consistence phenomenon either in S-tuning or in N-tuning for the playing sound and top-plate vibration, what can be concluded at this stage. The S-tuning raised semi-tone for each string causes the higher string tension affecting the pre-stressed effect on the top-plate, and thus the top-plate natural frequencies and frequency response are altered. The structural natural frequencies are changed, some were increased as shown in Figure 8, but the playing musical notes may vary the pitch frequency and do not always induce resonances. Therefore, the S-tuning does not always provide positive effects, in terms of brightness and loudness, for all musical notes. Next Section will present the spectral centroid to further clarify whether the S-tuning could actually have the advantage over the N-tuning.

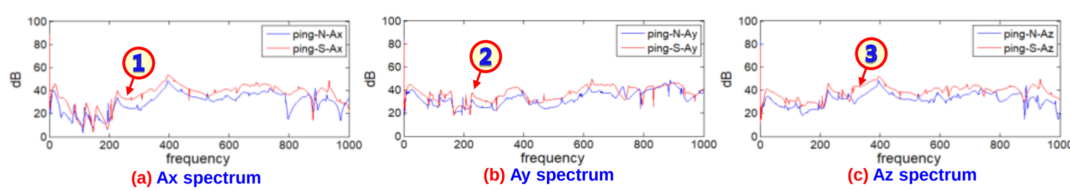


Figure 8: Top-plate vibration for different tuning methods by Ping-test: **Ax, Ay, Az Spectrum**.

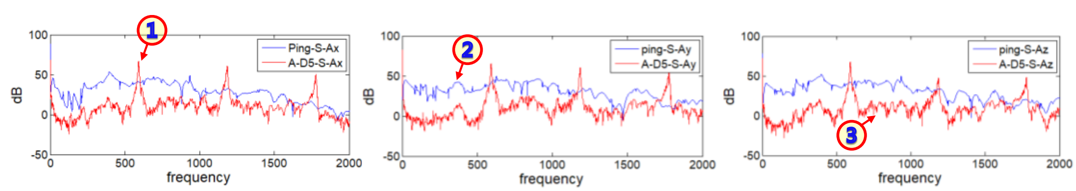


Figure 9: Comparison of top-plate vibration in In-playing and Ping-test for S- tuning.

4. Playing Mozart’s K.364 by S- and N-tuning

In previous Section, the study on the playing sound and top-plate vibration is for playing single note. The intention of this Section is to discuss the viola in the S- and N-tuning, respectively, for playing the first theme from the first movement in Mozart's K.364 as shown in Figure 2. Figure 10 shows the spectrogram analysis results by SM software for playing the Mozart’s piece. (1) In time waveforms, both S-and N-tuning cannot tell much difference. (2) The loudness level verse time plot clearly indicate the loudness in S-tuning is relatively higher than in N-tuning. (3) The overall averaged sound spectrum in 0-3000 Hz are not much different. The cause for the S-tuning with higher loudness than the N-tuning may come from spectral distribution for different musical notes. The further inspection on the spectrum is proceeded.

This work employs spectral centroid [11] to correlate the brightness of playing sound. The spectral centroid T_b is defined as follows:

$$T_b = \sum_{r=1}^{n} rP_r \bigg/ \sum_{r=1}^{n} P_r \,. \tag{1}$$

r is the r-th harmonics, P_r is the r-th peak response, and n is the number of harmonics. Figure 11 shows the spectral centroids of playing sound for the same notes in S- and N-tuning methods. Each string has been played for 7 musical notes as shown in Figure 1(b) and obtained for its T_b. (1) For A-string, there are 6 notes with higher T_b in S-tuning and 1 note in N-tuning. (2) For C-string, there are 2 notes with higher T_b in S-tuning and 5 notes in N-tuning. (3) Totally, the S-tuning with 61% (17/28) higher T_b is over the N-tuning with 31% (11/28). This result means there is higher possibility of the S-tuning obtaining brighter playing sound than the N-tuning. This also explains the non-consistent phenomenon observed in Section 3.

Finally, Figure 12 shows the comparison of T_b for playing Mozart's between the S- and N-tuning. Results show there are six notes out of eight have the higher T_b for S-tuning. This may explain the subjective evaluation that the S-tuning may have brighter and louder level of playing sound.

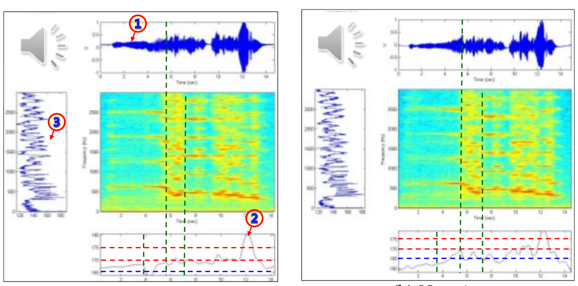


Figure 10: Comparison of playing Mozart between the S- and N-tuning methods.

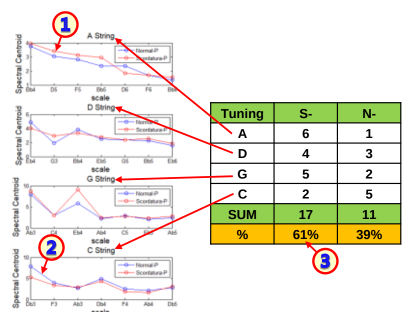
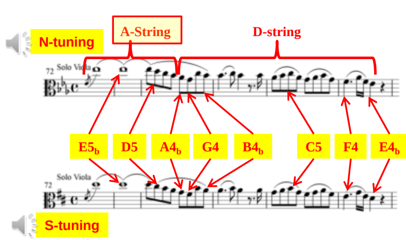


Figure 11: "Spectral Centroid" of playing sound for the same notes in S- and N-tuning methods.



Note	Freq. (Hz)	N-tuning (T_b)	S-tuning (T_b)
E4$_b$	312.0	2.14	2.84
F4	349.9	1.67	1.81
G4	395.0	2.80	3.61
A4$_b$	420.0	2.87	2.94
B4$_b$	464.8	2.62	2.75
C5	525.0	3.14	4.13
D5	585.0	4.03	2.53
E5$_b$	624.0	1.98	1.80

Figure 12: Comparison of "Spectral Centroid" for playing Mozart's piece between the S- and N-tuning methods.

5. Conclusions

The Scordatura (S) tuning is proposed by Mozart to alter the tuning of a string to a semi-tone higher than the standard or normal (N) tuning such that the playing sound of viola can be brighter with larger loudness. This study presents objective evaluation to show the difference of playing sound from the two tuning methods. Contributions and conclusions are as follows:

1. This work carries out two tests, i.e. In-playing and Ping-test. The developed experimental approaches to measure and analyze the playing sound and top-plate vibration are shown to effectively calibrate the differences between the S-tuning and N-tuning.
2. The objective evaluation of playing sound and top-plate vibration response via time waveform, spectrum and spectrogram can explain the cause of different tuning and may resolve the mystery why the S-tuning would result in brighter and louder sound characteristics.
3. Most importantly, the raised semi-tone for each string in S-tuning causes the higher string tension affecting the pre-stressed effect on the top-plate, and thus the top-plate natural frequencies and frequency response are altered. Although the structural natural frequencies are changed, some were increased, the playing musical notes may vary the pitch frequency and do not always incur resonance. Therefore, this change does not necessarily provide positive effects, in terms of brightness and loudness, for all musical notes.
4. Actually, some notes will reveal lower spectral centroid in S-tuning than that in N-tuning, but the S-tuning reveals higher percentage of musical notes with higher spectral centroids than the N-tuning. This may explain why the S-tuning could have brighter and louder sound than the N-tuning.

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