Perceived Pitch of Violin and Cello Vibrato Tones Among Music Majors

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Abstract:
The purpose of this study was to investigate the perceived pitch of string vibrato tones. The authors used recordings of acoustic instruments (cello and violin) to provide both vibrato stimulus tones and the nonvibrato tones that listeners adjusted to match the perceived pitch of the vibrato stimuli. We were interested especially in whether there were differences in pitch perception of vibrato tones between string performers (n = 36) and music majors without string performance experience (n = 36). Both groups of music major listeners perceived the pitch of vibrato tones very near the mean frequency of the vibrato for cello and violin tones. Although means were similar, string players exhibited significantly less deviation in tuning judgments than non-string players for both violin and cello tones. Results appear consistent with earlier perceptual research as well as performance research indicating that string performers vibrate both above and below the intended pitch.
Keywords: Vibrato; Perception; String instruments; String pedagogy

Article:
Vibrato is a skill that appears essential for the development of a mature sound in string playing. Many string players are able to perform with a beautiful vibrato but may be unable to articulate to others how the motion is produced. Although differences in vibrato rate and width between virtuoso solo performers and relative beginners can be easily discriminated, more subtle differences in individual components of vibrato are neither easily perceived by the ear nor easily seen. For example, it is difficult to ascertain initial direction of the vibrato motion, continuity during slurs, and rate or width variations affected by music context without the aid of slow-motion video or computer aided audio analysis (Geringer, Allen, & MacLeod, in press). Possibly because some attributes are not easily observed, pedagogical suggestions concerning some fundamental aspects are inconsistent; therefore, it seems constructive to approach the topic by reviewing pedagogical as well as empirical perspectives.

Perhaps the most commonly debated aspect of string vibrato is the pitch center and direction of vibration. Pedagogues and artists generally hold one of three views on the topic: (a) The vibrato oscillates from the in-tune pitch and above (Casals, cited in Applebaum, 1986), (b) the vibrato oscillates equally above and below the conceived pitch (Doschek, 1968; Joelson, 1964; Mantel, 1972; Rolland, Mutchler, & Hellebrandt, 2000; Young, 1999), or (c) the vibrato oscillates primarily from the in-tune pitch and below (Applebaum, 1986; Carroll, 1997; Fischer, 1997,2008; Galamian, 1962;Hamann & Gillespie, 2004; Lucktenberg, 1994; Suzuki, cited in Perkins, 1995).

Specific exercises designed to teach vibrato appear to be dependent on the author's approach concerning the direction of vibrato. For example, Fischer (2008) specified that the vibrato does not go around the pitch but, rather, only below the pitch. Fischer notated a vibrato exercise on the staff that instructs the student to oscillate from the in-tune note to a (sharp) half step lower. An identical exercise was included in Essential Techniques 2000 for Strings (Allen, Gillespie, & Hayes, 2004) and was recommended by Galamian (1962). Conversely, Fischbach and Frost (1997) notated vibrato exercises in such a way that would imply that the vibrato oscillates around the center of the pitch using both a forward and backward motion.

Views of pedagogues concerning perception of pitch in vibrato tones also appear to influence instruction. Galamian (1962) suggested that string vibrato oscillates from the pitch and below, otherwise the intonation will be perceived as sharp. Fischer (2008) recently echoed this view. Lucktenberg (1994) also suggested that students vibrate from the pitch and below because "the ear will invariably pick the highest pitch in a vibrato cycle, so if the tone goes both above and below the pitch, listeners will perceive the note as sharp" (p. 32).

In contrast, a number of pedagogues and performers of cello and bass seem to believe that vibrato oscillates around the center of the pitch (Doscheck, 1968; Mantel, 1972; Young, 1999). Mantel (1972) insisted that cellists vibrate around the center of the pitch, "thus, the tone that the listener hears is exactly in the middle between the extreme pitches of the vibrato" (p. 108). Furthermore, Applebaum (1986) stated that the pitch is a flattening motion in violin and viola performance, but apparently not for cello and bass. When questioned specifically whether arm vibrato oscillated below the pitch in a manner similar to that of hand vibrato, he responded, "Yes, only below the note, but this does not necessarily apply to the cello and bass" (p. 68).

Most empirical research concerning performance of string vibrato has found that the range of vibrato frequencies extends both above and below the intended pitch (Geringer & Allen, 2004; Geringer, Allen, & MacLeod, 2005; Seashore, 1938; Shackford, 1960; Small, 1936). Two sets of studies found that performed vibrato extended only from the intended pitch and above (Fletcher, Blackham, & Geertsen, 1965; Papich & Rainbow, 1974, 1975), and conversely, one study reported that vibrato extended only below the target pitch (Fletcher & Sanders, 1967). Two relatively recent studies were designed to measure the center of performed pitch in a vibrato using the performer's intended pitch as the reference point rather than using an external standard (Geringer & Allen, 2004; Geringer et al., 2005). Participants were instructed to perform the intended pitch without vibrato and then the same pitch with vibrato. The vibrated tone subsequently was compared to the performer's own nonvibrated tone. Both of these studies used high school and university violin and cello performers and demonstrated that the vibrato oscillated symmetrically around the intended center of the pitch. In an earlier study of professional violinists, Shackford (1960) used an electronically generated tone as a reference pitch and had performers vibrate in tune with the constant nonvibrated tone. The professionals (members of the Boston Symphony) vibrated equally above and below what they perceived to be the pitch of the reference tone.

Empirical studies also have been conducted with regard to the pitch that is perceived by listeners in frequency-modulated sounds such as vibrato. Most previous research has used electronic or synthesized timbres as source material rather than acoustic instruments (e.g., Iwamiya, Kosugi, & Kitamura, 1983; Seashore, 1938; Shonle & Horan, 1980; van Besouw, Brereton, & Howard, 2008) and found that perceived pitch corresponded to the mean of the frequency-modulated sounds. Shonle and Horan also found that perceived pitch of wider modulations (half- and whole-tone) corresponded more closely to the geometric mean of the extreme frequencies, a frequency slightly lower than the arithmetic mean. The investigation of van Besouw et al. (2008) concluded that the range of acceptable tuning for tones with vibrato was approximately 10 cents wider, predominantly in the flat direction, than tones without vibrato. S. Brown (1991) used both a variety of acoustic instruments and voices for stimulus presentations, although attack and decay portions of tones were eliminated and listeners responded by tuning an oscillator using a sawtooth waveform. Musicians located pitch of vibrato higher in frequency than nonmusicians.

We found only one study that used an unaltered acoustic string instrument for stimulus presentation. J. Brown and Vaughn (1996) recorded a professional violist performing with and without vibrato. The 11 listeners included 6 amateur musicians, 4 graduate violin students, and 1 professional violinist. Auditors used headphones and responded to 640 trials of paired comparisons wherein a vibrato tone was followed by a nonvibrato tone that was either higher in frequency than the vibrato tone or lower than the vibrato tone. Although the sample size was limited, results were consistent with most of the above empirical studies: Judged pitch of vibrato tones corresponded to the arithmetic mean of the vibrato.

Pedagogical materials continue to present inconsistent information with regard to both pitch perception and performance of string vibrato. Although empirical research generally has shown the perceived pitch of vibrato tones to be near the mean of the frequency modulations, we found no empirical study to date that used acoustic instruments both in stimulus presentations and in responses requiring active participation. Therefore, this study used acoustic instrument timbres for both stimulus and response aspects of the study, a unique extension of the research literature. The purpose of this study was to clarify the location of perceived pitch in string vibrato tones among music majors. We used acoustic instruments (cello and violin) in providing both stimulus tones and the tones that participants were asked to adjust to match the perceived pitch of vibrato stimuli. We were interested also in whether there were differences in pitch perception of vibrato tones between string performers and non-string music majors. Would both groups perceive the pitch of vibrato to be the mean frequency of the vibrato? How would the variability of responses compare between string and non-string performers? We also examined possible differences between cello and violin stimuli, participants with and without teaching experience, and males and females.

Method

Participants

Participants consisted of 72 music major students from one of two large schools of music located in Florida and North Carolina. Equal numbers of string instrument players (n = 36, which included string performance majors and string principals) and non-string instrument music majors were recruited on a volunteer basis from ensembles and classes in the music schools. The sample included 34 males and 38 females. Most students indicated that they did not have contractual experience teaching string class or orchestra (n = 50), compared to 22 who did have group string teaching experience. All procedures complied with institutional and federal regulations in the treatment of human subjects.

Performers

All tones used in the study were acoustic string tones recorded by two professional string performers. The violinist has a graduate degree from The Juilliard School, was assistant concertmaster of a well-known professional orchestra in the northeastern United States, and at the time of the study was teaching applied violin at a large state university. The cellist has a graduate degree from the Eastman School of Music, has professional orchestral and chamber music experience, and was teaching applied cello at a large state university.

Recording Process

Recordings were made in a studio designed for recording small ensembles and solo performers. Recording equipment included two AKG C 1000s condenser microphones, an Onyx 400F stereo preamplifier, and a Tascam HD-P2 digital audio recorder. Tones were recorded with a sampling frequency of 96 KHz and 24-bit resolution. Performers were brought to the recording room separately and were given time to warm up, accommodate to the room acoustics, and become familiar with the recording material and procedures. A metronome was used to give a general idea of the duration of tuning tones to be recorded but was turned off during the recordings. Performers used a tuning meter calibrated to A_4 = 440 Hz as a reference point. We asked each performer to provide four whole notes for each pitch suitable for providing a model for tuning (at an approximate tempo of quarter note = 60 bpm) with bow changes articulating the beginning of each whole note. When producing vibrato and stopped string tones, both performers used the second finger and thus played in third position. The violinist was asked to perform (a) open string D, $_4D_4$ (on the G string) with no vibrato, and D_4 (on the G string) with normal vibrato; (b) open string A_4, A_4 (on the D string) with no vibrato, and A_4 (on the D string) with normal vibrato; (c) open string E_4, E_4 (on the A string) with no vibrato, and E_4 (on the A string) with vibrato; and (d) B_4 with and without vibrato on the E string. Similarly, the cellist played (a) G_2 on the open G string and on the C string both with and without normal vibrato; (b) D_3 on the D string and on the G string with and without vibrato; (c) open string A_3 and with and without vibrato on the D string; and (d) E_4 with and without vibrato on the A string.

Preparation of Stimuli

The recorded sound files were transferred digitally to a computer for analysis and editing. Frequencies and amplitudes of all tones were analyzed with Praat (v. 5.0.05) software. Initial analysis of frequencies of the nonvibrato tones (open and stopped strings) showed that all violin and cello tones were within ±9 cents (most were within 5 cents) of their respective equal temperament frequencies relative to A = 440 Hz. We then adjusted the frequencies of the nonvibrato tones with Auto-Tune (v. 5.10) software so that all were within a deviation margin of ±1 cent. Initial analysis of the vibrato tones showed that mean frequencies of the performed vibrato tones were within 12 cents relative to equal temperament. We made adjustments in the mean frequency of the vibrato tones with Amazing Slow Downer (v. 3.1) so that means were all within ±1 cent (without changing the widths or rates of the performers). Subsequent analysis of the vibrato tones used in pilot studies and in the final experiment found cello vibrato rates of 4.9 Hz (G_2 and D_3) and 5.0 Hz (A_3 and E_4), with vibrato widths ranging from 20 to 28 cents (lower pitches had the slightly smaller widths). Final versions of the violin tones had vibrato rates of 5.0 and 5.1 Hz with widths ranging from 30 to 36 cents (lower tones had the smaller widths). We also made minor adjustments in amplitudes to provide approximately equal loudness levels of all vibrato and nonvibrato tones.

Pilot Studies

Pilot studies were conducted with graduate students who had performance experience in either upper (n = 10) or lower (n = 10) strings to test experimental stimuli, equipment, and procedures. We compared the ability of participants to tune nonvibrato tones to vibrato tones using either simultaneous or successive matching procedures. Successive matching was found to be more difficult and less accurate than simultaneous: Listeners needed multiple repetitions of tones and were not as confident that their tunings accurately reflected their pitch judgments. We compared tuning the vibrato tones to the nonvibrato tones as opposed to tuning the nonvibrato tones to the vibrated versions. The former procedure was more difficult and less relevant contextually; that is, string players generally tune their instruments by playing nonvibrato tones. Listeners verified that loudness levels were comparable and thought that they were more accurate (i.e., reflected what they were hearing) when tuning the nonvibrato stopped string tones rather than the open string tones to the vibrato tones. Several listeners commented that the timbral qualities of the stopped string tones matched the vibrato tones closer than the open string tones, and therefore, it was easier for them to find a closer match. Finally, we also tested several possible tuning ranges of the response dial and found that an overall range of ±50 cents (one-quarter tone in each direction) allowed a generous range of possible tunings that listeners might choose. Only a few students responded with tunings larger than ±20 cents.

Response Apparatus

Participants used the method of adjustment to indicate pitch perception of vibrato tones; that is, they turned an unmarked dial that controlled the frequency of the nonvibrato tones. Testing of listeners was done individually and took place in small quiet rooms (one in each school of music). Audio files were played by computer, amplified, and presented over stereo speakers (Audio Technica MMS 557B). The vibrato tone stimuli were presented in one speaker, and the nonvibrato tones in the other speaker. Listeners used a Continuous Response Digital Interface (CRDI) dial to raise or lower the frequency of the nonvibrato violin and cello tones. A recently developed version of the CRDI software enabled changes in dial position to instantaneously control frequency levels (without affecting duration) of the nonvibrato tones played with Amazing Slow Downer software. The CRDI dial was calibrated so that the full range of the dial (a 255-degree arc) corresponded to frequency changes of ±50 cents in the nonvibrato tone. We used a faceless dial that had no cues concerning pointer position, so that listeners were not able to ascertain visually the location of the middle of the dial. The only feedback, other than aural, concerning dial position was the dial stops at the two extreme endpoints (±50 cents). Because vibrato tones were modulating continuously in frequency and amplitude, listeners were unable to use "beats" as a tuning aid. Vibrato tones, which were heard simultaneously in the other speaker, were presented by another software program and could not be altered by listeners. All tones were set in "loop" mode for playback, so listeners would have no time limit in making adjustments.

Procedures

Participants heard 16 vibrato/nonvibrato pairs of stimuli. Each of the four cello tones (G_2, D_3, A_4, and E_4) and the four violin tones (D_4, A, E_4, and B_4) was presented twice: once with the nonvibrato tone initially presented 25 cents flat relative to the mean frequency of the vibrato tone and once initially presented 25 cents sharp to the vibrato tone. This was done to help control for possible effects of the direction of initial mistuning. We presented stimuli to listeners in one of four orders. The two string instruments (cello and violin) and the two directions of mistuning (sharp and flat) were counterbalanced: Listeners heard either the eight cello or eight violin tones first and either flat or sharp mistuning first.

Participants were informed that the purpose of the study was to investigate the location of the perceived pitch of string vibrato tones. They were told that their task was to change the frequency of the nonvibrating violin or cello tone by turning the dial until they were able to match the pitch that they heard in the vibrato tone. Listeners tuned a practice example to become familiar with the operation of the dial and the presentation routine. They were given the opportunity to ask questions and were told that they could take as much time as needed per pair of tones. All sessions including consent forms, instructions, practice, and tuning task for the 16 trials were completed in 22 minutes or less.

Results

Raw data consisted of participants' tuning adjustments (in cents) of the nonvibrato tones in response to the vibrato tones. To determine the frequency value of vibrato tones, we used the arithmetic mean of each tone as determined by Praat software, which we set to sample frequency every 2.5 milliseconds. If a listener adjusted the nonvibrato tone to a value near zero, for example, that would indicate that pitch perception was near the center of the vibrato for that tone. An adjustment about 15 cents in the sharp direction would indicate a perception of the vibrato pitch near the high point of the vibrato extent and 15 cents in the flat direction would indicate a perception of vibrato pitch near the low point of the vibrato. Table 1 shows the means and standard deviations of listeners' adjustments of nonvibrato tones. It can be seen that adjustment means were relatively close to zero: All mean tunings were within 1.6 cents of the mean of vibrato tones with the exception of violin A (M = -1.92 cents) tuned from the flat direction. Standard deviations ranged from about 5.8 cents to 9 cents. Thus, any listener responses that corresponded to the performed high or low extent of the vibrato tones (±10 to ±18 cents) would be between 1 and 2 standard deviations from the mean. The overall tuning means across all tones were within 1 cent of the vibrato means. The cello tone mean was -0.74 cents (SD = 3.11), and the violin tone mean was -0.77 cents (SD = 2.57).

We used an alpha level of .01 for all statistical comparisons. Raw data were screened and verified that assumptions of the analysis of variance were met. Preliminary analyses revealed that there was no significant difference in tuning adjustments between participants from the two universities, those with or without string teaching experience, or the four orders of presentation ($F < 1$), nor did these factors interact with any other factors. We then screened data to check assumptions of the multivariate analysis of variance (MANOVA) and confirmed normality, linearity, and homogeneity. Initial multivariate testing (with cello and violin responses as the variates) found no significant differences between the four individual notes from the two instruments, F(6,63) = 1.71, p > .13, or interactions of notes with other factors. Similarly, the effect of initial direction of mistuning had no significant main effect, F(2,67) < ,p > .49, or interaction with other variables. Therefore, data differentiating initial direction of tuning and individual notes were combined to produce two tuning responses for each individual, one for each of the instrumental stimuli.

A two-way multivariate analysis (with cello and violin responses as the variates) found a significant effect of gender, F(2,67) = 7.92, p < .01, partial n^2 = .19, and no significant effect of performance instrument experience (string vs. non-string instrument), F(2,67) = .78, p > .45, or interaction between gender and instrument, F(2,67) = 4.16,p > .02. A follow-up univariate analysis indicated significant differences between genders for cello, F(l, 68) = 11.19,p < .01, partial n^2 = .14, and for violin, F(l, 68) = 6.99, p < .01, partial n^2 = .09. Means of females were 2.2 cents higher than those of males for cello tones, and 1.6 cents higher on the violin tones.

In viewing boxplots of the tuning responses of string instrument performers versus those with non-string instrument experience, we observed that although means were similar, the distribution of scores of the latter group appeared consistently greater than for string performers. This provided evidence that string players' judgments deviated less from the center of the vibrato than judgments of non-string musicians. We then calculated 2 standard deviation scores for each listener, one derived from the eight violin trials, and a second based on the eight cello trials. Violin and cello standard deviation scores were linearly related, $r(72) = .46$, $p < .001$. We then used these two scores as variates in a two-way MANOVA, with gender and performance experience (string vs. non-string) as between-subjects variables. There was no significant difference for gender, $F(2,67) = .92$, $p > .40$, or interaction of gender with performance experience, $F(2,67) < 1, p > .80$. However, there was a significant multivariate effect for performance background, $F(2,67) = 18.03$, $p < .001$, partial $n^2 = .35$. Subsequent univariate tests found significant differences for cello tones, $F(l, 68) = 35.85, p < .001$, partial $n^2 = .35$, and for violin tones, $F(1,68) = 8.62$, $p < .01$, partial $n^2 = .11$. Mean scores are shown in Table 2 and demonstrate that mean deviations of participants with string instrument performance experience (M= 4.36) were smaller than deviations of non-string performers for cello tones (M= 7.54) and for violin tones (M= 5.33 and 7.0, respectively). Further analysis of individuals' standard deviation scores revealed no significant differences ($F < 1$) for orders, schools, or teaching experience.

Discussion

Main results of the study may be summarized as follows: (a) Music major listeners perceived the pitch of vibrato tones very near the center of the vibrato for cello and violin tones, not the high or low points of the vibrato extents, and (b) vibrato pitch perception means of listeners with string performance experience were similar to means of those with non-string experience, however, there was a significant difference between these groups in the distribution of scores. String players exhibited less deviation in tuning judgments than non-string players for violin and cello tones, and (c) there was a significant difference between male and female participants in pitch perception of cello and violin vibrato. Females' perceptions were sharper relative to males' mean pitch perceptions, although the magnitude of difference was small (about 2 cents).

Although both string performers and non-string performers perceived the pitch of vibrated strings very near the mean of the vibrato, the non-string music majors had a significantly wider range of responses. It is obvious that the string performers have more experience in making tuning adjustments with string tone stimuli, and this probably contributed to their more homogeneous responses. Teaching experience did not affect means or standard deviations of listeners, although the number of participants with teaching experience was limited. The present comparison should not be considered adequate for conclusions to be drawn. A significant difference was found between females and males in this sample; females perceived the pitch of vibrato tones about 2 cents higher than males. Whether this is musically consequential is arguable, because this magnitude of difference is below pitch discrimination thresholds even in optimal listening conditions (Spiegel & Watson, 1984). Further research is necessary to corroborate this finding and, if verified, to identify possible reasons for its occurrence.

Investigators in two studies suggested that listeners may hear the geometric mean, rather than the arithmetic mean, as the perceived center of vibrato tones, particularly with large vibrato widths (S. Brown, 1991; Shonle & Horan, 1980). Comparison of arithmetic and geometric means of the performed tones in this study indicated little difference between the two (as might be expected with vibrato widths of 20 to 36 cents): Geometric means were less than 1 cent below the arithmetic mean for all violin and cello tones. One could argue, and be technically correct, that because several of the perception means were 1 to 2 cents below the (arithmetic) mean of the vibrato tones, then those values correspond more closely to the geometric mean. However, a difference as small as 1 to 2 cents would have little practical consequence for musicians in a performance context (Spiegel & Watson, 1984).

These findings were consistent with J. Brown and Vaughn (1996) who reported that listeners judged the center of the vibrato tone as the perceived pitch. They used a paired-comparisons procedure with viola tones as source material. Results are consistent also with studies using electronic tones as stimuli (Iwamiya et al., 1983; Seashore, 1938; Shonle & Horan, 1980). Geringer and Allen (2004) and Geringer et al. (2005) detailed that university and high school cello and violin performers vibrate essentially equally above and below the intended pitch. This study provides additional evidence that listeners apparently perceive the pitch intended by the performer, that is, the mean of the performed vibrato extents.

Galamian (1962) asserted that performers should vibrate from the pitch and below, otherwise the intonation will be perceived as sharp. Similarly, Lucktenberg (1994) and others suggested that the ear picks out the highest point of the vibrato cycle, thus a flattening motion is recommended. In contrast, Mantel (1972) noted that cellists vibrate around the center of the pitch so that the tone the listener hears is the mean of the vibrato range. The results of this study seem to support Mantel's position, in the case of both cello and violin.

The findings of this study appear to have implications for current pedagogical practice. It seems likely that both performer intention and listener perception are consistent; that is, string performers generally vibrate equally above and below the intended pitch and listeners perceive the intended pitch of the string performer near the mean of the vibrato. Questions might be raised with regard to the efficacy of string pedagogues continuing to focus student attention on modulations exclusively below the intended pitch (Applebaum, 1986; Carroll, 1997; Fischer, 1997,2008; Galamian, 1962; Hamann & Gillespie, 2004; Lucktenberg, 1994; Suzuki, cited in Perkins, 1995), such as the common practice of recommending vibrato exercises for study with ancillary notes notated below the conceived pitch. It seems possible that this advice unnecessarily burdens students with concerns that perhaps have no basis in reality for either the performer or the listener.

Fischbach and Frost (1997) advocated an approach that uses vibrato exercises intended to develop the motion both above and below the intended pitch. This approach seems consistent with the findings of this study, for both the performer and the audience. However, it should be noted that we have found no empirical study that sought to determine the effectiveness of vibrato exercises that oscillate above and below conceived pitch compared to exercises that oscillate only from the pitch and below. Although vibrato apparently oscillates both above and below the intended pitch (Geringer et al., in press), it may turn out that it is beneficial to practice and emphasize the motion in the flat direction. A comparison of approaches to teaching vibrato to beginners would be useful to ascertain whether there are differences in vibrato characteristics between those taught to vibrate only below the conceived pitch and those taught to vibrate both above and below pitch. Furthermore, it would be useful to determine if there is any differentiation in learning efficiency between the two approaches and whether listeners are able to perceive any performance differences.

Future studies also might explore procedures that more closely replicate normal musical contexts concerning vibrato, tuning, and pitch matching tasks. For instance, the stimulus tone under both vibrated and straight tone conditions might be matched by performers on their own instruments, rather than manually manipulating the pitch by turning a dial as in this study. Additional investigations might explore the role of amplitude modulation both isolated from and in combination with frequency modulation in affecting vibrato judgments of listeners. It seems important to continue careful study of vibrato perception as well as vibrato performance and pedagogy because this is such an essential aspect of expressive string playing.

Table 1. Means and Standard Deviations of Listeners' Tuning of Nonvibrato Tones in Response to Vibrato Tones

Legend for Chart:

A - Tone (initial presentation)

B - Mean (cents)

C - Standard Deviation (cents)

A	B	C
Cello G (+25 cents)	-0.53	7.87
Cello G (-25 cents)	-1.38	8.02
Cello D (+25 cents)	-0.71	6.91
Cello D (-25 cents)	+1.01	8.61

Cello A (+25 cents)	-1.59	6.01
Cello A (-25 cents)	-1.13	6.02
Cello E (+25 cents)	-1.09	6.25
Cello E (-25 cents)	-0.52	5.79
Violin D (+25 cents)	-0.47	6.54
Violin D (-25 cents)	-1.31	5.25
Violin A (+25 cents)	-0.83	5.27
Violin A (-25 cents)	-1.92	6.05
Violin E (+25 cents)	-0.64	5.88
Violin E (-25 cents)	-1.56	7.27
Violin B (+25 cents)	+0.07	7.77
Violin B (-25 cents)	+0.50	8.97

Table 2. Means and Standard Deviations of Individual Listeners' Standard Deviation Scores

Legend for Chart:

A - Experience Group

B - Mean Deviation (cents)

C - Standard Deviation (cents)

A	B	C
Cello tones		
String performers	4.36	1.70
Non-string performers	7.54	2.65
Total	5.95	2.73
Violin tones		
String performers	5.33	2.35
Non-string performers	7.00	2.73
Total	6.17	2.67

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