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High School String Players' Perception of Violin, Trumpet, and Voice Intonation

Abstract

We studied young string players' perception of intonation in accompanied solo performances of trumpet, voice, and violin. We were interested in whether pitch deviations of equal magnitude in the three solo performances would be judged as equivalent in intonation. Listeners were 71 middle and high school string players who heard trumpet, voice, and violin performances of "Ave Maria" (Bach/Gounod) accompanied by piano. Pitch levels of the soloists were in-tune or became progressively more sharp or flat (by 10, 20, and 30 cents) relative to the accompaniment. Intonation changes in the sharp direction were judged as more out-of-tune for the violin than equivalent alterations of voice and trumpet. In flat direction changes, violin was also heard as slightly more out-of-tune than the other soloists for deviations of 30 cents, but was judged similar to the other two for deviations of 10 and 20 cents. Additional research is necessary to investigate whether this outcome was a result of these string players' heightened sensitivity to string intonation.

Keywords

string instruments, intonation, music perception, music performance, string music education

Myriad pedagogical literature addresses the importance of accurate intonation in ensemble performance (e.g., Crider, 1990; Kohut, 1973). Additionally, research suggests that listener responses to intonation can be predominant over responses to other elements of music (Geringer & Madsen, 1981, 1989, 1998; Johnson & Geringer, 2007). More informally, evidence of the magnitude of value given to tuning and pitch accuracy can be found throughout music behavior, for

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example: soloists, chamber and large ensembles tune before performing; music contests and festivals at all levels include intonation ratings on adjudication forms; performers evaluate new instruments on the basis of tone and intonation tendencies; teachers instruct students in alternate key or finger combinations to produce sometimes subtle pitch variations; and so on.

Acousticians, psychologists, and music educators have conducted a large number of studies in pitch perception and performance. For example, Geringer and Madsen (1987) summarized just one series of 16 studies relevant to both applied and experimental settings. Reports have addressed abilities from perspectives of both listener and performer. Accuracy in pitch discrimination and performance has been greater among more musically experienced and older participants (Duke, 1985; Geringer, 1983; Madsen, Edmonson, & Madsen, 1969). In general, musicians have shown greater acuity in detecting pitch deviations in the direction of flatness and indicate an overall preference for performances that are slightly sharp (Geringer & Madsen, 1981, 1989; Madsen, Edmonson, & Madsen, 1969; Madsen & Geringer, 1976, 1981). Further, investigators have noted the tendency to perform with sharp rather than flat deviation in many contexts (Geringer, 1978; Geringer & Madsen, 1987; Geringer & Witt, 1985; Kantorski, 1986; Madsen, 1974; Morrison, 2000; Salzberg, 1980; Sogin, 1989; Yarbrough, Morrison, & Karrick, 1997), although in some contexts a flatness tendency was noted (Brittin, 1993; Duke, 1985).

Substantial evidence exists that tone quality and intonation may interact in listeners' perception, and problems in one area may be confused with errors in the other (Geringer, Madsen, & Dunnigan, 2001; Madsen & Geringer, 1981). For example, listener responses have indicated a propensity to associate sharper intonation with "brighter" tone qualities and flatter intonation with "darker" tone qualities (Geringer & Worthy, 1999; Wapnick & Freeman, 1980; Worthy, 2000). In two studies of tuning performance, timbre affected the ability to match pitch (Ely, 1992; Greer, 1970). More recently, Byo, Schlegel, and Clark (2011) investigated timbre and octave of tuning stimuli on tuning accuracy of high school wind players. Tuning responses were least in-tune to the tuba tones compared to clarinet, flute, and oboe tones, even though most participants reported that tuning to the tuba was the most common method used when tuning their ensembles.

A number of researchers have documented that vibrato influences pitch perception, and some musicians have suggested that vibrato masks intonation errors (Metfessel, 1932). Yoo, Sullivan, Moore, and Fujinaga (1998) reported that listeners required more time to determine the pitch of violin vibrato tones compared to non-vibrato tones. Van Besouw, Brereton, and Howard (2008) found that advanced musicians judged the "range of acceptable tuning" as approximately 10 cents greater for vibrato tones than for non-modulated tones. Recently, Geringer, MacLeod, Madsen, and Napoles (2012) showed that music stimuli were heard as more out of tune when there was no vibrato compared to vibrato performances.

Of particular concern for string teachers and players is the pitch actually heard in vibrato tones. Early investigations of vibrato pitch used electronic sound sources rather than acoustical instruments. These studies showed that perceived pitch corresponds very closely to the mean of the frequency-modulated sound (Seashore, 1938). One study, however, noted that in very wide modulations (whole-tone or greater), perceived pitches corresponded to the geometric mean, slightly lower than the arithmetic mean (Shonle & Horan, 1980). In subsequent studies that used acoustic string instruments, perceived pitch of vibrato tones also corresponded very closely to the arithmetic mean of the vibrato (Brown & Vaughn, 1996; Geringer, MacLeod, & Allen, 2010), although vibrato tones may be heard a few cents (2-3) lower than non-vibrato tones of the same mean frequency (Geringer, MacLeod, & Ellis, in press).

A few researchers have noted possible differences in perception of intonation between different instruments as well as voice. Vurma and Ross (2006) found that trumpet and voice tones were judged as sharper than viola tones with the same fundamental frequency. Loosen (1995) investigated effects of experience performing on specific instruments on perception of accurate tuning. He reported that violinists tend to prefer sharper tuning of scales (closer to Pythagorean tuning) compared to pianists who preferred equal-tempered scales.

Loosen's 1995 results appear consistent with studies of intonation using string performers. Greene (1937) analyzed performances of six professional violinists and found that cent deviations fit closer to Pythagorean tuning than just or equal-tempered intonation. Nickerson (1949) found similar tendencies with a professional string quartet, in that performances most closely approached Pythagorean tuning, but concluded that performers did not completely conform to any of the tuning systems. This conclusion also corresponds with Loosen's 1993 study, in which violinists performed in-between Pythagorean and equal temperament tuning. Kopiez (2003) found evidence of a "burn in" effect demonstrated by two professional trumpet players. Their performances were closer to equal temperament than just intonation, which Kopiez attributed to long-term intonation practice with equal temperament.

Geringer et al. (2012) compared music majors' discrimination of intonation in *unaccompanied* melodies performed by trumpet, violin, and voice. They also examined whether there were differences between timbres in melodies performed with and without vibrato. Across all non-vibrato stimuli, violin was judged as more out-of-tune than voice and trumpet whether melodic intervals were in-tune, flat, or sharp. Melodies performed using vibrato were judged somewhat differently. Violin was judged as least in-tune for intervals mistuned in the flat direction, trumpet was heard as least in-tune for intervals mistuned sharp, and voice was perceived least in-tune when the intervals were in-tune (relative to equal temperament).

We designed the present study to investigate listener perception of intonation in *accompanied* solo performances of trumpet, voice, and violin. We were particularly interested in whether young string instrumentalists would judge intonation errors of equal magnitude in the three types of stimuli as equivalent or different in degree of mistuning. Given that investigators have found effects of specific instrumental experience on both performance and perception of intonation, we thought that perhaps string players' experience in listening to violin intonation would facilitate a heightened acuity to intonation errors in violin performances compared to voice and trumpet performances. On the other hand, since vibrato in trumpet is minimal, especially compared to the magnitude of frequency modulation in voice and violin, perhaps listeners would hear intonation errors in trumpet more readily. Specifically we asked whether middle and high school string players would judge the intonation in melodies differently between trumpet, violin, and voice soloists when performances of soloists were in-tune, sharp, or flat relative to the piano accompaniment.

Method

Participants

Participants in the study were 71 middle- and high-school string players (ages 12 - 17). These students were recruited during a summer music camp in a large school of music in the southeastern United States. All had studied with private teachers a minimum of three years and were considered at or above appropriate performance level for their age. There were 39 females, and 32 males. The sample included 35 violinists, 16 violists, 13 cellists, and 7 double bassists.

Preparation of Stimuli

We recorded trumpet, voice, and violin performances of the first 23 measures of *"Ave Maria"* (Bach/Gounod) accompanied by piano. We chose this piece because it has sustained notes, legato articulations, and clearly defined phrases. Sustained notes were important to facilitate listeners' perception of intonation. Recordings of the piano accompaniment were made in a large piano teaching studio with a Steinway B (7-foot) grand. The accompaniment was performed by a professional pianist, and was recorded in three different keys (D, E$^\flat$, and F major) as appropriate for the soloist recordings and to prevent listeners from accommodating to a single tonic when making intonation judgments. We analyzed the piano notes that were used in accompanying the excerpt in all three keys and found that frequencies conformed to standard tuning practices in equal temperament relative to A_4= 440 Hz (± 5 cents in the middle range). Recording equipment for both the accompaniment and solo performances included two AKG C1000S condenser microphones and a Tascam HD-P2 digital audio recorder. All performances were recorded at a sampling frequency of 48 kHz with 24-bit resolution.

Soloist performances were recorded in a studio designed for recording small ensembles and solo performers. Performers were brought to the recording room individually and were given time to warm-up, accommodate to the room acoustics, and become familiar with the procedures. The pre-recorded piano accompaniment was presented to performers by means of headphones, so that the solo performances could be recorded in isolation from the accompaniment. The three soloists were professional performers and were chosen on the basis of their known ability to perform with excellent intonation. The violinist performed the excerpt in the key of D major, the trumpeter in (concert) E♭ major, and the soprano vocalist in F major. All three performers made multiple recordings until both they and we were satisfied with the performance, particularly regarding intonation.

All recordings were transferred digitally to computer and the intonation of the performances was analyzed using Praat (Boersma & Weenink, 2010). Performances that conformed the most to the tuning of the piano were identified. We then edited the selected sound files with Adobe Audition (*v.* 4.0) and Auto-Tune (*v.* 7.09) software, in order to produce versions that contained pitches deviating no more than five cents from equal temperament. These versions were used as the master files for subsequent sound editing.

In order to provide contrast with the "in-tune" condition, we altered overall levels of intonation across 4-6 measure sections of the excerpt. The original four-measure piano introduction was truncated to two measures. The initial four measures of each solo performance (originally measures 5-8 of the piece) were always "in-tune," that is, not altered from the corrected master performance. This provided a model of what constituted "in-tune" for participants. Subsequent sections of the excerpt (measures 9-12, 13-17, and 18-23) were altered in the overall pitch levels of the soloists so that the sections as a whole were 10, 20, or 30 cents sharp, or 10, 20, or 30 cents flat, respectively, relative to the accompaniment. This was accomplished with Adobe Audition (*v.* 4.0) software. None of the examples contained both sharp and flat deviations; examples either remained unaltered (in-tune) throughout all measures, or became progressively sharper or flatter (in 10 cent increments for each section) through the excerpt. Each of the examples consisted of four sections, the first section of four measures was always "in-tune." The subsequent three sections remained in-tune or were ± 10 cents, ± 20 cents, or ± 30 cents relative to the accompaniment. A total of nine experimental examples were created, three for each instrument: one that remained unaltered, one that became progressively sharper, and one that became gradually flatter.

Procedures

The experimental examples were transferred to compact disc and presented in counterbalanced order to listeners using loudspeakers (M-Audio Studiophile AV

40). A prepared response sheet asked participants to indicate their instrument and their gender and provided instructions for the listening task:

> *Please use the following rating scale for all examples, and CIRCLE ONE number that corresponds to your perception of intonation between the soloist and the accompanist FOR THAT SECTION OF THE EXCERPT. You will rate 3 sections for each excerpt. You do not rate the first section (it has no numbers beneath the notation), because it will always be in-tune. The other 3 sections could be in-tune, or any degree of out-of-tune. First, we will do a practice example to make sure that you understand the directions.*

We used an 11-point rating scale, anchored with the words, "Very In-tune" at the low point of the rating scale (0), "Out-of-Tune" at the midpoint (5) and "Extremely Out-of-Tune" at the high point (10). Listeners were reminded to rate the intonation across the section and not to rate individual notes. A practice example (violin soloist playing in a different key) was provided at the beginning of the listening task, to allow participants to hear the excerpt and ask questions prior to the experimental examples. Each example on the response sheet consisted of the notated solo melody line for measures 5-23 (all shown in C major), with clear markers between the three sections with the rating scales provided: one rating scale each for measures 9-12, 13-17, and 18-23.

Results

Raw data consisted of listener ratings of intonation between the soloist and the accompanist. Table 1 presents the mean ratings for the three instruments across the three conditions of intonation change. When the intonation was not altered, that is, when the entire example was heard with good intonation, the overall mean was 1.64. Ratings showed little difference between instruments with voice being rated as the most in-tune (M = 1.40). Standard deviations were also consistent, ranging from 1.45 to 1.68. When the intonation was altered in the sharp direction, the violin was rated as the most out-of-tune (M = 3.80) with the highest standard deviation (1.84), followed by the trumpet (M = 2.57) and voice (M = 2.16). Alterations in the flat direction also resulted in the violin being rated the most out-of-tune (M = 2.96), although trumpet (M = 2.66) and voice (M = 2.63) were rated as only slightly more in-tune.

Table 1
Means of Judged Intonation for the Three Soloists across the Direction of Change

Direction of Change	Trumpet	Voice	Violin
No Change	1.72	1.40	1.81
Sharp Direction	2.57	2.16	3.80
Flat Direction	2.66	2.63	2.96

Note. Standard Deviations ranged from 1.45 to 1.84.

Table 2 displays mean ratings for the magnitude of alterations. In the unaltered condition, the three sections were rated similarly, though there was a slight increase in mean ratings from the first to the third section (1.57 to 1.71). Ratings in response to alterations in the sharp direction increased from a mean of 1.87 at 10 cents sharp, to 3.99 at 30 cents sharp. Changes in the flat direction were rated as more in-tune at 10 cents ($M = 2.05$) than at 20 cents ($M = 2.51$) and 30 cents ($M = 3.70$). Standard deviations ranged from 1.51 to 1.76.

Table 2
Means of Judged Intonation for the Magnitude of Deviation across the Direction of Change

Direction of Change	10 Cents	20 Cents	30 Cents
No Change (the 3 unaltered sections are shown)	1.57	1.65	1.71
Sharp Direction	1.87	2.38	3.99
Flat Direction	2.05	2.51	3.70

Note. Standard Deviations ranged from 1.51 to 1.76.

We used an alpha level of .01 for all statistical comparisons. Preliminary analysis showed that there was no statistical difference between female and male listeners ($F < 1$) or between the string instrument groups represented ($F < 1$), nor did these factors evidence interaction with other variables in the study. There was a violation of the sphericity assumption for the direction of change variable ($p < .01$); therefore we utilized a multivariate analysis of variance with the three directions as the variates (sharp, flat, and no change). Within subject variables were the three stimulus instruments (trumpet, violin, and voice) and the three magnitudes of change (10, 20, and 30 cents). Significant multivariate main effects ($p < .001$) were found for both the stimulus instruments and change magnitudes. However, the multivariate interaction between the two was also significant, F (12, 840) = 11.26, $p < .001$, $\eta^2_P = .12$. Subsequent univariate analyses of this interaction (alpha levels were adjusted for multiple comparisons) showed no significant differences in the no change measure, F (4, 280) = 2.90, $p > .02$. Significant interaction effects between the three instruments and the magnitude of change were found for the sharp direction alterations, F (4, 280) = 18.73, $p < .001$, $\eta^2_P = .21$, and for flat direction changes, F (4, 280) = 19.23, $p < .001$, $\eta^2_P = .22$.

The interactions are illustrated in Figures 1-3. Figure 1 demonstrates the no-change conditions, and reveals that intonation ratings for the trumpet, voice, and violin stimuli were similar across the segments. In the first two segments sampled, the voice was rated as slightly more in-tune than the violin and trumpet. Figure 2 depicts the sharp alteration conditions and indicates that the violin was heard as the most out-of-tune consistently at all three of the change magnitudes. Trumpet and voice stimuli were perceived similarly at 10 cents and 20 cents, but at 30 cents the trumpet was rated as more out-of-tune than the voice. Differences between voice and violin were almost three full points on the rating scale for the segment that was 30 cents sharp.

Ratings for alterations in the flat direction are displayed in Figure 3. It can be seen that at 10 cents and 20 cents mistuning, differences between the stimuli were small, with trumpet, then violin, then voice rated as the most in-tune. For the sections with alterations of 30 cents flat, however, the violin was rated the most out-of-tune, followed by trumpet and voice. Differences between violin and the other two stimuli were not as large in flat alterations compared to sharp alterations.

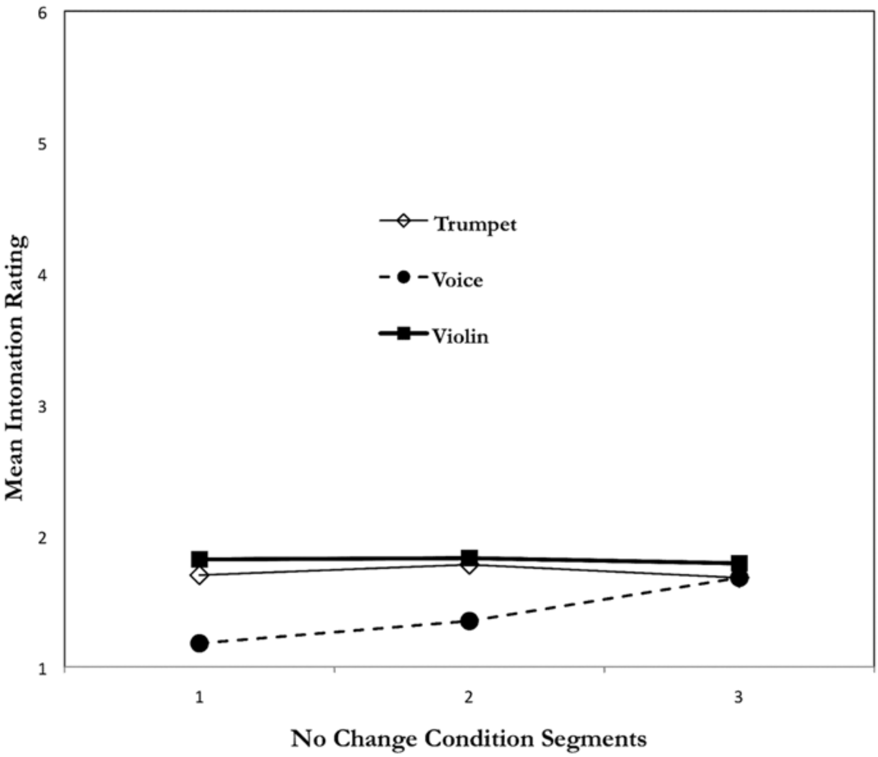

Figure 1. Mean intonation ratings for the three instruments in the no-change condition.

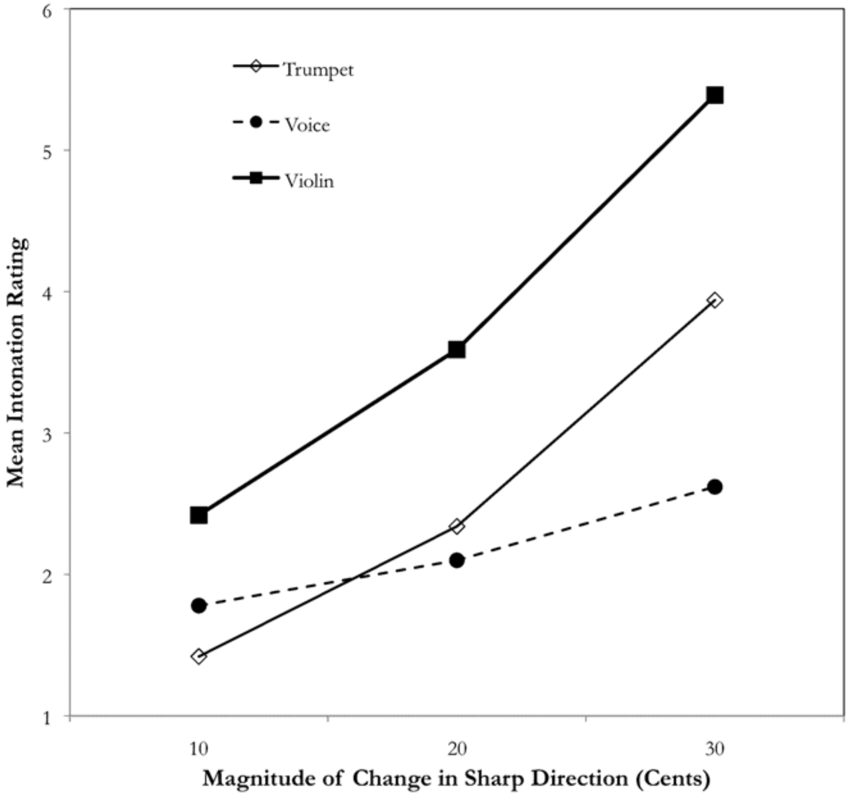

Figure 2. Mean intonation ratings for the three instruments in the sharp change condition.

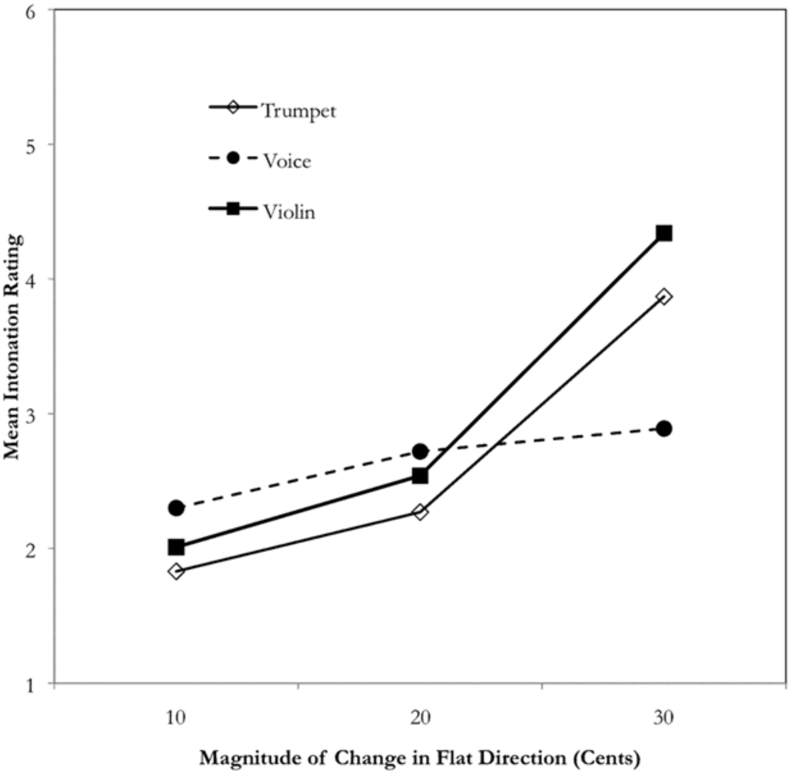

Figure 3. Mean intonation ratings for the three instruments in the flat change condition.

Discussion

The present study was designed to investigate young string players' perception of intonation in accompanied solo performances of trumpet, voice, and violin. We were interested in whether string instrumentalists would judge intonation errors of equal magnitude in the three types of performances as equivalent or different in magnitude of mistuning. When the example was presented with good intonation, there was little difference between the two instruments and voice. However, violin performances were judged as most out-of-tune for all three levels of deviation (10, 20, and 30 cents) in the sharp direction compared to the voice and trumpet performance excerpts. Violin excerpts were also rated as most out-of-tune for the largest magnitude of mistuning (30 cents) in the flat direction, but was judged similar to voice and trumpet for the smaller flat deviations (10 and 20 cents).

Participants in this study were middle and high school age string players and both experience level and primary instrument may have impacted their judgment of intonation. It is possible that the students were more discriminating or critical with respect to the violin excerpts compared to trumpet and voice excerpts because they were more familiar with the timbre of string instruments and/or more critical of instruments that are the same (about half of the participants were violinists) or similar to the instrument that they study.

Overall, the participants judged each excerpt as more out-of-tune as the excerpt progressed. Participants correctly identified the excerpts as being more out-of-tune during the portions of the excerpts that were 30 cents sharp or flat compared to the excerpts that deviated by 10 and 20 cents. Mean intonation perception for the 10 cent deviations were not very different from in-tune stimuli indicating that within a musical context, this magnitude of change may be near or within the discrimination threshold for these listeners. This response pattern provides a degree of authenticity to the stimuli since larger deviations were judged as progressively more out-of-tune than the smaller magnitudes of deviation. It should be noted that these relatively young students may have perceived examples as out-of-tune at least in part because their attention was directed to intonation. It is possible that merely suggesting that a passage may be out-of-tune caused the participants to be highly sensitive to intonation. It is also possible that equal temperament tuning itself may not be heard as "in-tune" for one or more of the instruments in this study (*cf.*, review of literature). Variations in individuals' concepts of "in-tune" may partially account for some in-tune excerpts to be judged as slightly out-of-tune and, further, why violin, voice, and trumpet were judged differently across the various magnitudes of deviation.

Previous research has found greater listener acuity in detecting intonation errors that were flat compared to sharp (e.g., Geringer & Madsen, 1987; Madsen, Edmonson, & Madsen, 1969). Participants in this study rated the flat deviations as more out-of-tune for excerpts that were 10 and 20 cents flat compared to the excerpts that were 10 and 20 cents sharp. However, participants rated the 30 cent sharp intonation excerpts as slightly more out-of-tune than the 30 cent flat excerpts. This appears to be due primarily to the perception of intonation in the violin excerpt: Students perceived the sharp violin performance as being much more sharp and out-of-tune than the corresponding voice and trumpet excerpts. The piano accompaniment in the recordings, which was not altered from the original tuning, provided a harmonic foundation for the melody and likely assisted the participants in perceiving the intonation alterations of the soloists that gradually increased in magnitude. Further research that investigates pitch perception in various contexts (melodic as well as harmonic intonation) might clarify some of the differences found in this study. A number of other possibilities may be addressed as well: Perhaps participants perceived a difference in intonation between the three instruments because the timbre of the instrument affected their perceptions. It is possible that the participants' primary instrument and experience level affected their intonation judgment. More advanced musicians may perceive intonation differently.

The results of this study should not be generalized outside the context of middle and high school string musicians. Further research should investigate pitch perception of more advanced instrumentalists in a comparative way between stimuli, as well as a broader range of instrumentalists before conclusions regarding possible differences between instruments can be drawn. Differences may exist with other timbres and/or tessitura, such as cello, viola, trombone, or male voice. A number of other related questions seem important in this line of research: How do listeners of other music backgrounds perceive intonation deviations? Are trumpeters more sensitive to trumpet intonation, and vocalists to intonation of singers and so on? Are musicians with more advanced training than these participants sensitive to intonation more equitably across soloists? Are judgments of pianists and other instruments with fixed pitch less sensitive to differences between soloists? What role does the type and extent of vibrato play in discrimination of intonation? Further research that addresses questions such as these seems essential to help in understanding this important area of music performance and teaching.

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