Perception of melodic intonation in performances with and without vibrato

By: John M. Geringer, Rebecca B. MacLeod, Clifford K. Madsen, Jessica Napoles

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Abstract:

We compared perception of mistuned intervals in unaccompanied melodies performed by trumpet, violin, and voice, and examined whether there were differences between the three timbres in performances with and without vibrato. Participants were 144 university music students. Listeners heard the three unaccompanied solo performers in two vibrato conditions (with and without vibrato), and three intonation conditions (selected melodic intervals were in tune, sharp 25 cents, or flat 25 cents relative to equal temperament). All three stimuli were perceived as more out of tune when there was no vibrato compared to vibrato. In performances without vibrato, violin was judged as more out of tune than voice and trumpet across all three tuning conditions. Melodies performed with vibrato were judged 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 judged least in tune when intervals were in tune (relative to equal temperament). Differences in perception between timbres may be influenced by characteristics of the vibrato itself such as modulation width, rate, and type.

Keywords: instruments | intonation | melodic intervals | timbre | vibrato | voice

Article:

Pitch perception and the ability to perform with good intonation are considered among the most important aspects of musicianship. One can observe the value placed on intonation and pitch perception through the ubiquitous inclusion of intonation ratings on adjudication forms at music contests, festivals, and auditions. Instrumental music teachers place emphasis on tuning prior to the beginning of rehearsals and many music students spend hours practicing with the assistance of an electronic tuner. Not only is the importance of accurate intonation during solo and ensemble performance emphasized by pedagogues (e.g. Crider, 1990; Fischer, 2009; Kohut, 1973), researchers have found that listeners evaluate performance quality based largely on intonation compared to other musical elements (Geringer & Madsen, 1981, 1989, 1998; Johnson & Geringer, 2007).

A number of contextual variables appear to affect perception of pitch and what is perceived as “in tune,” including: melodic and harmonic context, presence or absence of accompaniment, timbre, register, instrument type, and the use of vibrato. In some ways, the concept of “good” or “accurate” intonation remains somewhat equivocal. Performing with accurate intonation, or sounding “in tune,” can be challenging even to the most experienced performer. Pedagogical views and teaching practice frequently promote the use of one temperament system over another for specific instrument families, although there is limited empirical evidence to support the claims. For example, investigators have studied whether string instrument performances align with Pythagorean tuning (Greene, 1936; Nickerson, 1949), or wind instruments might fit closest to Just tuning (Kopiez, 2003; Leukel & Stoffer, 2004). In order to better understand perceived differences in intonation accuracy between instrument families, we designed the present study to investigate listener perception of melodic intonation in unaccompanied violin, trumpet and voice solos, in performances with and without vibrato.

Researchers have endeavored to examine the perspectives of both listeners and performers and developed a large body of research related to pitch perception and performance. Geringer and Madsen (1987) offered a summary of 16 empirical studies related to pitch, and these were reported as one series among several others, with relevant applications to pedagogues and researchers. Compared to less experienced musicians, musically-experienced and older participants have demonstrated greater acuity both during pitch discrimination tasks and while performing (Duke, 1985; Geringer, 1983; Madsen, Edmonson, & Madsen, 1969). Generally, participants have indicated a preference for intonation deviations that are sharp as opposed to flat and have demonstrated greater acuity in detecting pitch deviations in the direction of flatness (Geringer & Madsen, 1981, 1989; Madsen, Edmonson, & Madsen, 1969; Madsen & Geringer, 1976, 1981). Correspondingly, this preference for sharpness is also present with performers, whose tendency to perform sharp has been documented in a number of studies (Geringer, 1978; Geringer & Madsen, 1987; Geringer & Witt, 1985; Madsen, 1974; Morrison, 2000; Salzberg, 1980; Sogin, 1989; Yarbrough, Morrison, & Karrick, 1997). In some contexts, college wind players performed intervals less sharp than less-experienced wind players (Brittin, 1993; Duke, 1985).

Melodic and harmonic context appear to impact the performers’ intonation as well as the listeners’ perception of intonation. Researchers have compared the intonation of excerpts performed unaccompanied or without harmonic context to those performed with harmonic context and results from these studies have varied (Ballard, 2011; Bell, 1995; Brittin, 1993; Duke, 1985; Geringer, 1978; Kantorski, 1986; Leukel & Stoffer, 2004; Madsen, Geringer, & Heller, 1991; Mason, 1960; Rasch, 1985). For example, Leukel and Stoffer (2004) investigated the intonation tendencies of major and minor thirds performed by four professional flautists in accompanied and unaccompanied conditions. They found that harmonic context affected the intonation of minor thirds more than major thirds. Conversely, Mason

(1960) compared the intonation of unaccompanied solo wind instrument performances to wind ensemble performances and found few, if any, consistent differences between the two performances. However, he did conclude that woodwind quintet performances were significantly affected by the harmonic structure of the music. Duke (1985) measured performed intonation of middle school, high school, and college wind players and found no significant difference in intonation between intervals played with and without a harmonic context.

Investigators have focused on intonation of string players and vocalists and identified differences between accompanied and unaccompanied performances as well (Bell, 1995; Kantorski, 1986; Madsen et al., 1991; Papich & Rainbow, 1974). Bell (1995) found that listeners were able to discriminate intonation deviations of vocalists more quickly when harmonic context was present. Intonation deviations were also identified more quickly when they occurred in the melody (Bell, 1995; Brittin, 1993). Both Kantorski (1986) and Madsen et al. (1991) found significant differences in tuning between performances with harmonic context compared to those without. Papich and Rainbow (1974) found that string players adjusted pitch more during ensemble performances than when performing solo.

Substantial evidence exists to indicate that there is an interrelationship between tone quality and intonation. When presented with varied combinations of good or poor intonation or tone quality, listeners did not always correctly identify where the errors occurred (Geringer, Madsen, & Dunnigan, 2001; Madsen & Geringer, 1981). Researchers have reported a listener association between brighter tone qualities and sharper intonation, and a corresponding association between darker tone qualities and flatness (Geringer & Worthy, 1999; Wapnick & Freeman, 1980; Worthy, 2000). Timbre affected participants’ ability to play in tune; performing with like timbres produced the least intonational deviations (Ely, 1992; Greer, 1970). More recently, Byo, Schlegel, and Clark (2011) investigated timbre and octave of tuning stimuli on the tuning accuracy of high school wind players. Participants tuned more accurately to the clarinet, flute, and oboe stimulus tones than to the tuba tones, despite the fact that the majority of participants reported tuning to the tuba in their ensembles.

Some researchers have investigated the possibility that different instruments or families of instruments tend to correspond more closely to a specific tuning system: equal temperament, Pythagorean, or Just (Greene, 1936; Karrick, 1998; Kopiez, 2003; Leukel & Stoffer, 2004; Loosen, 1993, 1995; Mason, 1960; Nickerson, 1949). Greene (1936) analyzed the intonation of six professional violinists and found that cent deviations conformed to none of the tuning systems; however, performances were generally sharp and 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 he concluded that performers did not completely match any of the tuning systems. The conclusion that string players do not completely fit any of the tuning systems was corroborated by Loosen (1993), when he analyzed the intonation of eight professional violinists and found that their intonation fell between Pythagorean and equal tempered tuning.

Similar studies have been conducted examining the intonation of wind instrumentalists and results have been inconsistent (Kopiez, 2003; Leukel & Stoffer, 2004; Mason, 1960). Leukel and

Stoffer (2004) found some conformity to Just tuning for minor thirds in a harmonic context, while Mason (1960) found a lack of conformity to any of the formal intonation systems. Kopiez (2003) measured the intonation of two profession trumpet players and found that their intonation most closely aligned with equal tempered tuning.

Listener perception of intonation relative to the three main tuning systems has revealed similar outcomes to studies of performers' tendencies. Loosen (1995) investigated the effect of musical experience on listener intonation preference and found that violinists preferred sharper tuning of scales (closer to Pythagorean tuning) compared to pianists who preferred equal-tempered scales, while non-musicians had no preference.

Regarding possible effects of vibrato on intonation, Metfessel (1932) suggested that vibrato can disguise out of tune playing. Others (Van Besouw, Brereton, & Howard, 2008; Yoo, Sullivan, Moore, & Fujinaga, 1998) agreed that vibrato affects listener perceptions of pitch. In particular, Yoo et al. (1998) found that listeners had more difficulty identifying violin pitches when performed with vibrato. Van Besouw et al. (2008) studied the "range of acceptable tuning" for advanced musicians, and this range was approximately 10 cents greater for vibrated tones than for non-vibrated tones.

We found only a few studies that directly compared instrument families with regard to perception of intonation. Vurma and Ross (2006) noted that listeners judged trumpet and voice tones as sharper than viola tones despite the fact that the examples contained identical fundamental frequencies. Similarly, Geringer, MacLeod, and Sasanfar (2012) investigated high school listeners' perception of accompanied voice, violin, and trumpet examples and found that the violin was judged as more out of tune compared to trumpet and voice performances with the same pitch deviations.

We designed the present study to investigate listener perception of melodic intonation in unaccompanied solo performances with and without vibrato. Specifically, we examined whether university music students would judge the intonation in melodies differently in vibrato versus no-vibrato conditions and between trumpet, violin, and voice soloists when performances of melodic intervals were in tune, sharp, or flat relative to equal-tempered intervals.

Method

Participants

Participants in the study were 144 undergraduate and graduate university music students. All were recruited from music classes and ensembles at three large schools of music in the southern, eastern, and western regions of the United States. Female students numbered 86 (60%) and there were 58 (40%) males, percentages that approximate the proportion of females (58%) and males (42%) enrolled in the music schools. All students had completed a minimum of 2 years of college-level music study. We obtained responses from students whose private music study included the following applied areas: voice ($n = 45$), wind instruments ($n = 56$), string instruments ($n = 32$), and keyboard ($n = 11$).

Preparation of stimuli

We recorded unaccompanied solo trumpet, voice, and violin performances of the first four measures of *Twinkle, Twinkle Little Star* (this melody is known widely as *Ah! Vous dirais-je, Maman*). We wanted a selection in which intonation errors could be easily identified: this excerpt is well known, has sustained notes, and contains typical common practice intervals. Pilot investigation that compared listener responses across the intervals in the melody confirmed the utility of the selection.

We recorded solo performances in three (concert) keys (D, E♭, and F major) as appropriate for the soloist recordings and to prevent listeners from accommodating to a single tonic when making intonation judgments. Recording equipment for 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.

Performances of the excerpt with and without vibrato were recorded in a studio designed for recording small ensembles and solo performers. The three soloists were experienced professional performers, and were chosen after consultation with applied music faculty and based on their ability to perform with excellent intonation. 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. All three soloists were given a tuning tone (relative to A-440) in accordance with the tonic key of their recording. Recordings of the excerpt were made using a lightly detached articulation in comfortable tessitura and keys for each soloist: The violinist performed the excerpt in the key of D major, the trumpeter in (concert) E♭ major, and the soprano vocalist in F major. The vocalist used the syllable [*mi*] in place of the usual words. All three performers made multiple recordings of vibrato and no-vibrato performances until both they and we were satisfied with the accuracy of their performance, particularly with respect to intonation.

All recordings were transferred digitally to computer and the intonation of the performances was analyzed using Praat (Boersma & Weenink, 2012). We then selected the most "in tune" performances (relative to equal temperament) of each vibrato and no-vibrato version for each soloist, and edited the sound files with Adobe Audition (v. 4.0) and Auto-Tune (v. 7.09) software, in order to produce versions in which all pitches deviated no more than three cents from equal temperament. We used these versions as the master files for subsequent sound editing.

We did not alter the first four notes (scale degrees 1 & 5) of the excerpt in order to provide an in tune model for the balance of the excerpt. We conducted pilot studies (N = 45) to help ascertain the appropriate magnitude and number of mistuned intervals. We found that melodic intervals made sharp or flat by 20 cents were occasionally identified as "in tune" (especially for scale degrees 3 & 4) and that subsequent notes were also heard as "out-of tune" rather than the one that was mistuned. Because we were interested in judged magnitude of intonation errors between timbres and between vibrato conditions, we wanted mistuned intervals to be discriminable. Therefore, we increased the magnitude of mistuning to 25 cents sharp or flat, and decided to include two intonation alterations per example on two different scale degrees. The three remaining scale degrees (2, 5, and 6) in the excerpt were found to be of comparable ease of identification. The two mistuned intervals per example included two of those three scale degrees and were counterbalanced across timbres, direction of mistuning, and vibrato condition.

We used Adobe Audition (v. 4.0) software to accomplish the intonation manipulations. Mistuning of the two scale degrees within a given example was either in the sharp or flat direction, not both. A total of 18 experimental examples were created, six each for trumpet, violin, and voice. Half of the examples used vibrato, and half did not. Two examples per timbre (one with vibrato and one without) contained alterations that were 25 cents flat, two were 25 cents sharp, and two examples remained unaltered from the master “in tune” version. Four orders of presentation were produced that counterbalanced presentation order of soloists, vibrato condition and direction of deviation.

Procedures

Experimental examples were transferred to compact disc and presented to listeners in groups of 5–20 using studio quality loudspeakers (e.g. M-Audio Studiophile AV 40). A prepared response sheet requested participants to indicate their year in school, instrument/voice and gender, and provided instructions for the listening task:

You will hear the first 4 measures of “Twinkle” as shown on your sheet. Examples are not necessarily in that key, the melody is given merely as a reference. In all examples, the first measure is always “in tune”, as is the last note. Any of the other notes could be sharp, flat, or in tune. After you hear an example, you are to indicate whether the whole example was “in tune” (by circling in tune on your sheet for that example), or whether one or more notes were “out-of tune”, and the degree of mistuning that you perceive (from slightly to very out of tune). If you decide that one or more of the notes were not in tune, then also please circle whether you heard the note (or notes) as sharp, flat, or that you couldn’t tell (by circling “?”). If more than one of the notes is out of tune, they will always be in the same direction (there are no mixed flat and sharp examples).

We used a 5-point rating scale, anchored with the words, “in tune” at the low point of the rating scale (0), “slightly out of tune” (below number 1), “out of tune” at the midpoint (2), and “very out of tune” (centered below numbers 3 and 4). To the right of the rating scales were the response choices for direction: sharp, flat, and a question mark. Two practice examples (violin and trumpet examples in different keys) were provided at the beginning of the listening task, to allow participants to hear the excerpt and ask questions prior to the experimental examples. The notated solo melody line for the first four measures of *Twinkle* (shown in C major) was at the top of the response sheet.

Results

Raw data consisted of participants’ intonation ratings and judgments regarding direction of mistuned intervals. Table 1 presents means and standard deviations of listener ratings for instruments, vibrato and no-vibrato performances, and the direction of mistuning. Also shown are percentages of correct identification of the mistuned intervals. It can be observed that all three timbres were perceived as more out of tune when presented with no vibrato. All means were higher (indicating more judged deviation from "in tune") in no-vibrato performances than vibrato presentations of comparable timbre and direction, with only one exception (the voice "in tune" examples). Among the no-vibrato examples, violin was perceived as less in tune than trumpet and voice for sharp, flat, and in tune presentations. For the stimuli with vibrato, the trumpet was rated as most out of tune for examples that contained sharp mistuned intervals, the violin for flat intervals, and the voice for presentations that were in tune (unaltered from master versions that approximated equal temperament). Listeners' correct judgment percentages regarding direction of mistuning were not consistently higher in either vibrato or no-vibrato performances of the trumpet or violin. However, judgments for the voice presentations were more correct in no-vibrato examples.

Table 1. Means, standard deviations, and percentage correct identification for direction of mistuning in vibrato and no-vibrato examples.

Instrument/Voice	Vibrato			No vibrato		
	Sharp	Flat	In tune	Sharp	Flat	In tune
Trumpet						
Mean	1.99	1.36	0.59	2.31	1.78	0.76
SD	0.88	0.94	0.81	1.07	0.91	0.90
% Correct direction	58%	64%	58%	58%	71%	47%
Violin						
Mean	1.75	1.61	0.56	2.61	2.56	1.17
SD	0.99	1.07	0.75	0.96	1.10	1.08
% Correct direction	65%	60%	56%	66%	53%	31%
Voice						
Mean	1.26	1.27	1.14	1.76	2.12	0.97
SD	1.01	1.13	0.85	1.06	1.10	1.09
% Correct direction	38%	61%	22%	66%	75%	43%

We used an alpha level of .01 for all statistical comparisons. Preliminary analyses showed that there was no statistical difference between any of the between-subjects variables: female and male listeners, type of private music study, sites of administration, or the presentation orders ($p > .20$), nor did these factors evidence interaction with other variables in the study. Testing of the sphericity assumption showed significant violations for the three timbres and the interaction of timbre and direction of change ($p < .001$). Therefore we used a multivariate analysis of variance with the three timbres as the variates. There were two within-subjects variables, vibrato condition (vibrato vs. no-vibrato performances) and direction of change (sharp, flat, and no change).

We found significant multivariate effects for vibrato condition, $F(3, 141) = 58.55$, $p < .001$, $\eta_p^2 = .55$. Subsequent univariate analyses showed significant differences (after adjusting for multiple comparisons) between vibrato and no-vibrato conditions for all three timbres, $F(1, 143) \geq$

21.60, $p < .001$. Effect sizes were smaller for trumpet and voice ($\eta_p^2 = .131$ and .134, respectively), than for violin ($\eta_p^2 = .537$). As can be seen in Table 1, means for judged violin intonation were almost a full standard deviation higher for the sharp and flat performances with no-vibrato examples than for the same examples with vibrato. Means for voice and trumpet were also judged as more out of tune with no vibrato, but the magnitude of difference was generally less than half a standard deviation.

Significant multivariate effects were also found for direction of mistuning, $F(6, 568) = 75.84$, $p < .001$, $\eta_p^2 = .45$. Univariate analyses showed significant differences for all three timbres, $F(2, 286) \geq 46.00$, $p < .001$. Effect sizes for trumpet ($\eta_p^2 = .539$) and violin ($\eta_p^2 = .505$) were larger than for voice ($\eta_p^2 = .243$). The trumpet was judged as significantly more out of tune for sharp intervals ($M = 2.15$) than for flat intervals of the same magnitude ($M = 1.57$), and for unaltered intervals ($M = 0.68$). Violin was perceived approximately the same for sharp and flat intervals ($M = 2.18$ and 2.09, respectively), which were significantly different from judgments of unaltered intervals ($M = 0.87$). Perceptions of intervals with voice timbre showed sharp and flat intervals were rated somewhat similarly ($M = 1.51$ and 1.73, respectively) and significantly different from unchanged melodic performances ($M = 1.05$).

The interaction of timbre and direction of change also revealed significant effects, $F(6, 568) = 9.50$, $p < .001$, $\eta_p^2 = .091$. Follow-up univariate tests showed a significant effect for voice examples, $F(2, 286) = 26.74$, $p < .001$, $\eta_p^2 = .158$, but not for trumpet or violin ($p > .10$). For the latter two timbres, all three directions of change were heard as more in tune when performances used vibrato. Voice performances were also heard as more in tune when vibrato was used for sharp and flat mistuned intervals, especially for flat mistuning (vibrato $M = 1.27$, no-vibrato $M = 2.12$). However, when the voice performance was not altered from the in-tune version, the no-vibrato performance was perceived as more in tune ($M = 0.97$) than the vibrato version ($M = 1.14$).

Discussion

Music majors rated mistuned intervals as more in-tune when performers used vibrato. This result provides additional support for the idea that vibrato helps mask intonation inaccuracies (Yoo et al., 1998; Van Besouw et al., 2008). Violin was perceived as the most out of tune in no-vibrato performances for all three tuning conditions: sharp, flat, and in-tune. There were differences in perception between the timbres in performances with vibrato. Trumpet was heard as most out of tune for intervals mistuned sharp, violin was judged most out of tune for flat intervals, and voice as least in tune in the unaltered intervals. Among possible factors for these perceptions may be the characteristics of the vibrato itself such as modulation width, rate, and duration. For example, trumpet vibrato, unlike voice and violin vibrato, is characterized more by amplitude modulation than frequency modulation. The influence of typical performance tendencies of the instruments and voice may be a factor as well. It is interesting to note, however, that the no-vibrato version (not usually heard in solo voice performance) of the unaltered “in tune” voice performance was judged as slightly more in tune than the performance with vibrato. Perhaps the lack of vocal vibrato made it easier for listeners to hear that the performance was “in tune”. This was the only comparison in which the performance without vibrato was judged as more in tune than the corresponding vibrato performance. Future investigation might study perception of intonation using additional instruments that characteristically do not use vibrato to the extent used by vocalists and string performers, as well as in performance styles where vibrato is used minimally.

Percentages of "correct" identification of the direction of mistuning (which ranged from 38% to 71% in mistuned intervals) may seem somewhat low. However, when one note of an ascending melodic interval was mistuned 25 cents sharp, then the subsequent interval became relatively smaller (flatter) by the same magnitude. Therefore a participant's judgment of flat would not necessarily be incorrect, as it may indicate that the listener responded with a slight delay to the altered note.

Researchers have substantiated the issue of context in listening, including listener discrimination of intonation. One might consider a fundamental question: If something is "in tune" or "out of tune," exactly what is it in tune or out of tune with? Even musicians with "perfect pitch" must be "perfect" to some standard such as A = 440; indeed, "perfect" is not an abstraction outside of a comparison. Only when comparing one pitch to another does one have a problem with intonation, such as when a chorus drops pitch across time and the piano or orchestra resumes after a long interlude. If the accompaniment could drop to the same exact level as the now flat chorus, perhaps no one would notice. However, researchers have noted that matching pitches of different instruments and voices to an electronic tuner does not always result in identical perception of intonation (Geringer et al., 2012; Vurma & Ross, 2006). Further, the most pronounced difference(s) among the three intonation standards, Just, Pythagorean, and equal-tempered appear miniscule compared to those found in a number of empirical studies (cf. review of literature) demonstrating that musicians often do not perceive differences when listening within a musical context.

One critical issue concerns vertical listening, such as getting the "beats" out of unisons or when comparing two simultaneous tones, versus horizontal listening. Listeners sometimes tolerate large variations within context in unaccompanied melody examples. Although musicians may perceive even slight differences of 3–4 cents in vertical (simultaneous) comparisons, advanced musicians apparently cannot perceive differences as large as a minor third if they are nested within a musical context and if the music very gradually gets sharper or flatter across time (Madsen & Geringer, 2004). Comparisons of intonation tendencies between different instruments or of the variations among tuning standards do not appear to account for the differences in perception or performance found in melodic versus harmonic contexts (Ballard, 2011; Ely, 1992; Geringer, 1978; Papich & Rainbow, 1974).

The present study indicates that vibrato can mask a multitude of intonation errors and make even out of tune examples less noticeable (as perhaps some popular vocalists have demonstrated for years). Earlier research has shown a wider range of acceptability for vocal performances using vibrato (van Besouw et al., 2008). Lindgren and Sundberg (cited by Sundberg, 1979) used different tunings of a vocal performance, and musically-experienced listeners were asked to identify tuning errors. Their experienced listeners accepted errors as large as 50–70 cents as in tune; listeners were tolerant especially when mistuned notes were sharp, in metrically unstressed locations, and when found in emotionally prominent points in the song.

Future research should extend this study within a harmonic (vertical listening) context. It would be of both practical and theoretical interest to ascertain the extent to which accompaniment may affect perceived intonation in vibrato and no-vibrato performances. The presence of the accompaniment may differentially affect how listeners judge the magnitude of mistuning of different instruments and voice. Because listeners often do evaluate the quality of music performances on perceived intonation, it is important for music educators and teachers to understand how listeners, as well as those who are performing, judge tuning accuracy within a musical context.

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