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# Effects of Vibrato and Pitch-Varied Vocal Models on Acoustic Measures of High School and Undergraduate Singers' Vocal Performance

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## Abstract

The primary purpose of this study was to investigate the effects of vibrato and pitch-varied vocal models on high school and undergraduate singers' intonation and use of vibrato. The secondary objective of this research was to examine participants' perception of vocal models to explore a possible relationship between perception and production. Participants ($N$ = 76) were undergraduates ($n$ = 40) participating in a choral ensemble at a large university and high school students ($n$ = 36) currently enrolled in a nearby choral program. Male ($n$ = 38) and female ($n$ = 38) participants responded to 12 same-gender vocal models, stimuli that varied in melody, vibrato, and intonation conditions. Model singers recorded vocal models without accompaniment on the neutral syllable "tah" in both vibrato and minimal vibrato conditions. Select pitches were mistuned ±25 cents to create the pitch-varied models. High school and undergraduate singers showed differences in vibrato rate, vibrato extent, and intonation in response to vibrato-varied models. Both groups also showed differences in response to pitch-varied models, with flat models producing the greatest deviation in pitch. Participants indicated on a post-stimuli questionnaire that they perceived differences in vibrato more readily than in intonation.

**Keywords:** *singing accuracy, pitch accuracy, intonation, vibrato, vocal models, choral pedagogy, perception, performance*

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# Effects of Vibrato and Pitch-Varied Vocal Models on Acoustic Measures of High School and Undergraduate Singers' Vocal Performance

Successful singing involves a number of perceptual skills, including that of pitch matching (Loui et al., 2015). Joyner (1969) described pitch matching as a complex task in which singers must discriminate, perceive, and recall pitches, all the while being able to vocally reproduce and adjust as needed. Over the years, researchers have labeled singers with pitch deficiencies as *monotone, poor pitch, uncertain,* and *inaccurate* singers. Investigators found that such singers matched pitch less accurately (Price, 2000), transposed pitches and intervals (Pfordresher & Brown, 2007), and sang with restricted vocal ranges (Phillips et al., 2002). Suggested causes of these issues include a "mismapping" between pitch target and production (Pfordresher & Brown, 2007) and a deficiency in motor skills processes (Phillips et al., 2002). Remedial training has been somewhat effective, particularly in extending pitch range and in increasing the accuracy of single note and interval production (Joyner, 1969; Roberts & Davies, 1975). Individual and small group sessions have also improved singing accuracy (Rutkowski & Miller, 2003), particularly when used as a part of focused instruction (Demorest et al., 2018).

Researchers have observed singing accuracy to be higher in older versus younger children (Cooper, 1995; Geringer, 1983; Goetze, 1989; Horbach & Taggart, 2005; Yarbrough et al., 1991) and in females over males (Goetze, 1989; Green, 1994). Regarding stimuli timbre and octave, elementary singers matched pitch more accurately to female and male falsetto models (Small & McCachern, 1983; Yarbrough et al., 1991), but most accurately to child models of a similar timbre (Green, 1990). In research investigating K-8 uncertain singers' responses to male, falsetto, and sine wave models, Price et al. (1994) observed females matched more often to upper octave stimuli and male singers to lower octave stimuli. In a follow-up study with K-8 male participants, Yarbrough et al. (1995) observed eighth-grade males matched more often to lower octave stimuli, whereas K-7 males were more accurate with upper octave stimuli. In both studies (Price et al., 1994; Yarbrough et al., 1995), singers sang less accurately in response to sine wave models. Similar to responses with K-8 singers (Price et al., 1994), Williams (1994) observed high school singers responded more accurately to models of the same gender and in the same octave.

Researchers have also examined how task variables may affect singing accuracy. Pitches presented within a tonal context produced differences in singers' pitch accuracy (Demorest & Clements, 2007; Geringer, 1983), although researchers found the presence of accompaniment had no significant effect (Guilbault, 2004; Hedden & Baker, 2010). Children were generally more accurate in their performance of short patterns over songs (Demorest et al., 2018), although Guerrini (2006) observed that familiarity with either task had no effect on increasing pitch accuracy. Results varied when children sang in solo versus doubled singing conditions, although researchers speculated that many factors contributed to findings (Nichols & Lorah, 2020). Given the number of influencing variables, Nichols (2016a) asserted that singing accuracy may be unique to the specific task and that the use of multiple singing assessments that include tasks from the teaching process would produce the most accurate view of singers' skills (2016b).

In choirs with older and more developed singers, the issue of vibrato may also influence singers' accuracy. Vibrato is a phenomenon typically associated with Western classical singing, with descriptive parameters of rate, extent, regularity, and waveform (Sundberg, 1995). Researchers identified the presence or absence of vibrato as a consistent difference between professional and untrained singers (Brown et al., 2000) and also observed that trained singers sang less accurately when performing with vibrato in an operatic style (Larrouy-Maestri et al., 2014a; Larrouy-Maestri & Morsomme, 2014). Investigators found that formal training and vocalization affected vibrato, as did the musical elements of pitch, duration, and intensity (Bretos & Sundberg, 2003; Michel & Myers, 1991; Mitchell & Kenny, 2010; Mürbe et al., 2007; Prame, 1994). Variations in vibrato also occurred when singers used imagery or emotional expression (Dromey et al., 2015; Moorcroft et al., 2015; Scherer et al., 2015). Singers have demonstrated the ability to adjust vibrato rate and extent to match target stimuli (Dromey et al., 2003; King & Horii, 1993; Titze et al., 2002), as well as reduce vibrato rate and extent within choral settings (Jers & Terström, 2005; Mann, 2014; Rossing et al., 1987).

Seashore (1932) conducted several studies on vibrato, reporting that several illusions exist mostly in regard to pitch. Investigators have observed the perceived pitch of vibrato tones to be the mean fundamental frequency (Brown & Vaughn, 1996; Sundberg, 1972) and that vibrato tones could be out of tune by 10 cents or greater, but still not perceived as such by expert listeners (Larrouy-Maestri et al., 2014b; Van Besouw et al., 2008; Vurma & Ross, 2006). Researchers also found that listeners judged the voice differently than instruments, particularly when vibrato was present, and that judgments in vocal intonation were more forgiving (Geringer, MacLeod, Madsen, & Nápoles, 2015; Geringer, MacLeod, & Sasanfar, 2015).

Researchers have evaluated singing accuracy using both subjective and objective analysis methods (Larrouy-Maestri et al., 2013). While investigators have documented perceptual analysis to be reliable (e.g., Guerinni, 2006), acoustic analysis has provided a more consistent measurement of singers' skills (Larrouy-Maestri et al., 2013). In studies utilizing acoustic analysis methodology, researchers used software (e.g., *Praat, AudioSculpt*) to segment the auditory signal and extract the fundamental frequency of specified pitches (e.g., Larrouy-Maestri & Morsomme, 2014). Researchers have chosen to segment pitches in various ways, including the steady-state portion of a note (e.g., Nichols & Wang, 2016), a vowel within a syllable (e.g., Dalla Bella et al., 2007), or the entire pitch, including the onset of the tone (e.g., Pfordresher & Brown, 2007). Once segmented, researchers have evaluated pitches for accuracy and/or precision (e.g., Pfordresher et al., 2010) and compared sung pitches to target stimuli using variable or fixed (e.g., 100, 50, 25 cents) deviation cut-off ranges as criterion (Dalla Bella, 2015). Other analysis parameters have included melodic contour and tonality (e.g., Larrouy-Maestri & Morsomme, 2014), as well as energy distribution, vibrato rate, and vibrato extent (e.g., Larrouy-Maestri et al., 2014b). Although acoustic analysis has shown to be reliable in assessing untrained and occasional singers (Dalla Bella, 2015), researchers contend these methods may not be fully reliable in assessing singing with complex vibrato sounds (Larrouy-Maestri et al., 2013; 2014a; 2014b).

While researchers have investigated vibrato singing in various contexts, only a few specifically examined singers' responses to vibrato stimuli. Yarbrough et al. (1992) explored the effects of adult female and child models on the pitch accuracy of K-3 singers. Uncertain singers responded more accurately to the non-vibrato female model, whereas certain singers showed a high level of accuracy in response to all models. In a second study involving vibrato stimuli, researchers studied the effects of synthetic vibrato and timbre-varied models on the pitch accuracy of female collegiate and professional opera singers, ages 20 – 55 (Duvvuru & Erickson, 2016). Duvvuru and Erickson reported no differences in pitch accuracy in response to vibrato models, although singers attempted to match the timbre of vibrato stimuli.

Vocal model studies to date have involved elementary and/or middle school age singers, with only one known study using high school participants (Williams, 1994). Further, while researchers examined the effects of vibrato models with elementary children (Yarbrough et al., 1992) and older more trained female singers (Duvvuru & Erickson, 2016), I found no research with high school and undergraduate participants of both genders. As these singers likely represent a majority of those participating in secondary and university choral programs, research examining this population's response to various vocal models may provide knowledge for choral educators to deliver more effective instruction. Hence, this study attempted to explore the effects of vibrato and pitch-varied vocal models on acoustic measures of male and female high school and undergraduate singers' vocal performance. The following questions guided this research:

1) Is singers' intonation affected by vibrato or pitch-varied vocal models?
2) Is singers' vibrato rate affected by vibrato or pitch-varied vocal models?
3) Is singers' vibrato extent affected by vibrato or pitch-varied vocal models?
4) Do singers perceive differences between vocal models?

# Method

## Participants

I initially recruited 96 volunteer participants from four choral ensembles at a large university ($n$ = 50; 25 males, 25 females) and from two choral classes at a nearby high school choral program ($n$ = 46; 20 males, 26 females). Prior to the study, I obtained appropriate IRB permissions from the university and public-school system, as well as consent from participants and high school parents. After participation in the study, I eliminated 10 undergraduates (five male, five female) and 10 high school singers (two male, eight female) for a lack of response to all vocal models and/or inaccuracies in pitch matching (i.e., measured sung pitch

> 90 cents from target stimuli pitch). The final sample used for data analysis was 76 singers.

Undergraduates ($n$ = 40) self-identified as 20 males and 20 females, ranging from 18 - 25 years in age ($M$ = 19.6, $SD$ = 1.78). Undergraduates reported 0 – 8 years in private voice study ($M$ = 3.75, SD = 2.72) from high school to the present time and 4 - 12 years choral experience ($M$ = 7.4, $SD$ = 2.12) since middle school. Six undergraduates were non-majors and 34 were music majors, 30 of whom listed voice as their primary instrument. High school participants ($n$ = 36) self-identified as 18 males and 18 females and ranged from 14 - 17 years in age ($M$ = 15.91, $SD$ = 0.93). All participants sang in first period Mixed Chorus, with the exception of three males who sang in Men's Chorus later in the day. High schoolers reported 0 - 4 years private voice study ($M$ = 0.5, $SD$ = 1.18) and 1 - 7 years choral experience ($M$ = 4.41, $SD$ = 1.69) since middle school.

## Model Melodies and Model Singers

As researchers (Demorest et al., 2018) suggested the use of multiple tasks in singing assessments, I selected a pitch pattern and song excerpt for the model melodies. The pitch pattern was a common melody found in choral music (*sol-la-sol-fa-mi-re-do*) and the song excerpt was the first phrase of the children's song, "Are You Sleeping?" Both melodies move primarily in stepwise motion, with intervals in the song excerpt rated as easy or moderate in task difficulty in research with elementary singers (Wolf, 2005). I also chose a practice pattern (*do-re-mi-fa-sol*), as researchers recommended the use of at least one practice item on singing assessments (Nichols & Wang, 2016). I chose the keys for the model melodies (D and E♭ major) and practice pattern (E major) in consultation with expert voice teachers and the high school choral director, decisions which took into account participants' age and vocal development. Figure 1 on the next page displays the model melodies and practice pattern.

As researchers observed some high school singers and male changed voices responded more accurately to models of the same gender and in the same octave (Price et al., 1994; Williams, 1994; Yarbrough et al., 1995), I choose an adult male and female singer to record the model stimuli. I initially selected three male and three female adult singers, in an attempt to find a male and female singer with similar vibrato characteristics. All singers recorded model melodies three times in both vibrato and minimal vibrato conditions. I analyzed all recordings for mean vibrato rate (VR) and vibrato extent (VE) using *Praat v. 6.0.19* (Boersma & Weenink, 2016) and selected the one male and one female singer with the most similar vibrato characteristics in both conditions to record the final stimuli. The male model singer was a 48-year-old baritone with experience as a professional singer and audio engineer (vibrato models: VR $M$ = 5.95 Hz, $SD$ = 0.075, VE $M$ = 84.03 cents, $SD$ = 1.75; min vibrato models: VR $M$ = 2.96 Hz, $SD$ = 0.37, VE $M$ = 10.28 cents, $SD$ = 0.43). The female model singer was a 58-year-old soprano with a professional singing background, as well as 32 years of experience as a choral director (vibrato models: VR $M$ = 5.17 Hz, $SD$ = 0.045, VE $M$ = 102.89 cents, $SD$ = 1.47; min vibrato models: VR $M$ = 2.83 Hz, $SD$ = 0.095, VE $M$ = 12.67 cents, $SD$ = 2.39).

## Recording and Editing of Vocal Models

I recorded model singers at a 44.1 kHz sample rate and 16-bit depth, using a MacBook Pro (Mac OS X Version 10.7.3; Apple, Cupertino, California), *Audacity 2.1.2,* and a Snowball model condenser microphone with a USB digital output (Blue Microphones; Westlake Village, California). Model singers performed stimuli with legato articulation at approximately 60 bpm on the neutral syllable "tah" to allow for an open sound with observable vibrato. Model singers sang without accompaniment or harmonic context, so that participants' focus would be solely on the intonation of the model singer.

Model singers made multiple recordings of each model melody in vibrato and minimal vibrato conditions. After analysis of all recordings (*Praat v. 6.0.19*), I selected the vocal model in each vibrato condition with the most accurate intonation in relation to equal temperament (ET) for further editing. Using *Adobe Audition* v. 4.0, I created the "in-tune" models by adjusting all pitches to be within three cents of ET. From these audio files, I created the pitch-varied models by mistuning specific 3rd or 5th scale degrees sharp or flat by 25 cents relative to ET (see Figure 1 for mistuned pitches). To manipulate pitches within *Adobe Audition,* I used the iZotope Radius algorithm set to high precision with the Stretch and Pitch Special Effects module. After manipulations, I re-analyzed pitches (*Praat v. 6.0.19*) to confirm that corrections and mistunings were accurate. The result of all editing was 12 vocal models for each model singer, stimuli that presented in two melody conditions (pitch pattern, song excerpt), two vibrato conditions (vibrato, minimal vibrato), and three pitch-varied conditions (in-tune, sharp, flat).

For the practice example, both of the model singers made multiple recordings in the vibrato condition only. I analyzed all practice example recordings for intonation (*Praat v. 6.0.19*) and selected the most in tune recording relative to ET for each model singer. There were no corrections or manipulations made to practice item recordings.

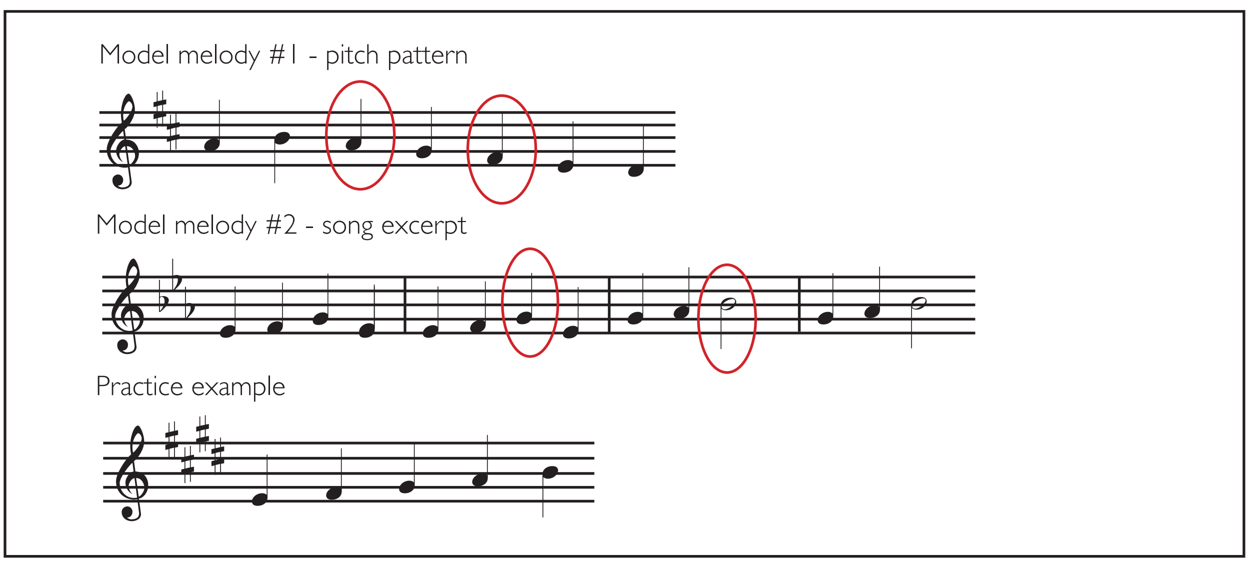


**Figure 1**
*Model melodies with mistuned pitches (± 25 cents) circled and practice example.*

## Final Preparation of Vocal Model Stimuli

To control for order effect, I designed four presentation orders of the 12 vocal models, each counterbalanced by vibrato, intonation, and melody conditions. I then created four audio files for each model singer to correspond with the four presentation orders (*Audacity 2.1.2*). All audio files began with pre-recorded instructions prompting participants to "imitate vocal models, as if your choral director has asked you to do so." The appropriate gender practice example followed these instructions, along with silent response time. After the practice example, additional pre-recorded instructions cued participants that the models were about to begin. I then inserted the 12 edited vocal models in the appropriate presentation order, along with silent response time after each vocal model. In an attempt to clear participants' tonal memory after each vocal model, I inserted excerpts that were between 3 – 4 seconds of Morton Subotnick's "The Wild Bull." Once preparation was complete, I saved audio files in WAV format, uploaded them to iTunes, and transferred files to iPad (Mac 3rd Generation, Version iOS 9.3.5; Apple, Cupertino, California).

## Testing Room Set Up and Equipment

I tested undergraduates in a university music research room and high school participants in an ensemble room within their high school. While the two testing rooms were not acoustically equivalent, I made every attempt to replicate the set up between facilities. Both rooms were approximately 300 sq. feet in size and had carpet on the floor and walls. I laid down a line of masking tape on the floor approximately two feet in front of a table to denote where participants should stand when recording. I placed a 1-foot high box in the center of the table with a Snowball USB condenser microphone (Blue Microphones; Westlake Village, California) on top, and two Bose multi-media speakers (Companion 2, Series II; Bose Corp., Framingham, MA) positioned approximately six inches on either side angled towards the participant. Both the microphone and speakers were approximately three feet from participants. Behind the microphone box and in front of my chair, I placed a MacBook Pro laptop (Mac OS X Version 10.7.3; Apple, Cupertino, California) and an iPad (Mac 3rd Generation, Version iOS 9.3.5; Apple, Cupertino, California).

## Procedure

Undergraduates sang in the late morning or afternoon and I asked these singers to warm-up before arriving. High schoolers sang between 7:45-8:30 am and the high school choral director provided them with a 15-minute group warm-up prior to testing. Upon arrival, I assigned each singer an audio file in a way intended to balance presentation orders between genders and groups. Before testing, I provided singers with written instructions and the model melodies notated in treble or bass clef. Singers stood on the line of masking tape and listened to the appropriate audio file via iPad and Bose multi-media speakers, through an Equalizer App (EQLZR PRO, Version 2.7, acoustic preset) for enhanced listening conditions. I recorded singers' responses using the MacBook Pro laptop, *Audacity 2.1.2* and the

Snowball USB condenser microphone. I set the microphone to record in a cardioid pattern and made monaural recordings at a sample rate of 44.1 kHZ and 16-bit resolution. During testing, I provided no help except to cue participants to respond after vocal models. Afterward, participants completed a written questionnaire that gathered information on their musical experience. As the secondary purpose of this research was to explore participants' perception, I designed the final two open-ended items on the questionnaire to assess if participants perceived differences between vocal models and to allow them the opportunity to describe perceived differences using terminology of their choice.

## Data Analysis

Using *Praat 6.0.19* (Boersma & Weenink, 2016), I acoustically analyzed WAV format recordings of participant responses for intonation, vibrato rate, and vibrato extent, with only the two mistuned pitches in the pitch-varied models (see Figure 1) analyzed in each model response. I segmented a steady-state portion of the pitch, with full vibrato cycles selected whenever possible. In an attempt to avoid irregularities in oscillations, I did not include the onset and release of individual pitches.

For purposes of reliability, I randomly selected and re-analyzed 20% of participant responses for all dependent measures (intonation $r = .91$, vibrato rate $r = .86$, vibrato extent $r = .89$). During initial intonation analysis, I analyzed segments for mean fundamental frequency (F0), data which I later converted to cents deviated from the F0 for statistical analysis; I therefore deemed "agreement" during reliability analysis as any F0 measurement within the same whole number value as the initial F0 measurement (e.g., initial $M = 442.03$ Hz, re-analysis $M = 442.08$ Hz). Similarly, I defined agreement for vibrato extent as any peak-to-trough measurement within the same whole number value as the initial measurement (e.g., initial $M = 55.02$ cents, re-analysis $M = 55.06$ cents). As the range of vibrato rate data ($M = 1.16 - 6.95$ Hz) was smaller than other data sets, I defined agreement as any frequency of oscillations measurement within a tenth-place value of the initial measurement (e.g., initial $M = 5.21$ Hz, re-analysis $M = 5.27$ Hz).

I conducted a repeated measures ANOVA for all analyses, with gender (male, female) and participant experience (high school, undergraduate) serving as between-subjects variables and model melody (pattern, song excerpt), model vibrato condition (vibrato, minimal vibrato), model intonation condition (in tune, sharp, flat), and analyzed scale degree (3rd, 5th) serving as within-subjects variables. I initially included vocal model presentation order as a between-subjects variable in all analyses, but later eliminated this variable when I found no order effects ($p > .05$). Mauchly's test indicated no violation in the assumption of sphericity for all analyses ($p > .05$). Given the multiple within-subjects data points, I chose a more conservative alpha level of .01 for all analyses. For analysis of the final perception item on the questionnaire, I identified and coded terminology reflecting vocal technique and/or musical elements and then counted these keywords for frequency of response.

## Results

### Research Question One: Intonation

Raw data consisted of individual pitch analysis in the form of cents deviation from the fundamental frequency in relation to equal temperament (ET) tuning. I coded directional pitch deviation data as a positive or negative value to reflect direction of intonation (i.e., sharp or flat in relation to ET). There was a main effect for the vibrato condition of models, $F(1, 72) = 12.80$, $p = .001$, $\eta_p^2 = .15$, with responses to vibrato models ($M$ = -7.61 cents, $SD$ = 18.35) found to be less flat than responses to minimal vibrato models ($M$ = -11.80 cents, $SD$ = 14.71). There was a main effect for the intonation condition of models, $F(2, 144) = 17.35$, $p < .001$, $\eta_p^2 = .19$, with flat models producing the greatest pitch deviation ($M$ = -12.30 cents, $SD$ = 16.19) and sharp models producing the least pitch deviation ($M$ = -6.88 cents, $SD$ = 16.14). Post hoc pairwise comparison between models showed significant differences ($p = .006$) between responses to sharp and in tune models (mean difference = 3.05 cents, $SD$ = 8.23), as well as significant differences ($p < .001$) between sharp and flat models (mean difference = 5.41 cents, $SD$ = 8.21). I also observed a main effect for participant gender, $F(1, 72) = 15.03$, $p < .001$, $\eta_p^2 = .17$, with male participants ($M$ = -16.75 cents, $SD$ = 22.42) responding with more flatness than female participants ($M$ = -2.66 cents, $SD$ = 22.38). A two-way interaction occurred between participant gender and intonation condition of models, $F(2, 144) = 5.72$, $p = .004$, $\eta_p^2 = .07$. Females sang more out of tune in response to flat models ($M$ = -3.51 cents, $SD$ = 23.02) than in response to in tune ($M$ = -3.38 cents, $SD$ = 24.29) and sharp models ($M$ = -1.10 cents, $SD$ = 22.87). Male singers also responded more out of tune to flat models ($M$ = -21.08 cents, $SD$ = 22.90) than to in tune ($M$ = -16.49 cents, $SD$ = 24.17) and sharp models ($M$ = -12.66 cents, $SD$ = 22.76), but with overall greater flatness than females. Figure 2 on the next page displays the interaction.

### Research Question Two: Vibrato Rate

Raw data consisted of vibrato rate analysis of individual pitches, as measured by frequency of cycles per second (Hz). There was a main effect for the vibrato condition of models, $F(1, 72) = 33.75$, $p < .001$, $\eta_p^2 = .31$, as vibrato rates were faster in response to vibrato models ($M$ = 5.22 Hz, $SD$ = 0.43) than to minimal vibrato models ($M$ = 4.99 Hz, SD = 0.40). A two-way interaction occurred between gender and participant experience, $F(1, 72) = 7.12$, $p = .009$, $\eta_p^2 = .09$. Mean vibrato rates of male undergraduates ($M$ = 5.24 Hz, $SD$ = 0.71) were faster than female undergraduates ($M$ = 5.04 Hz, $SD$ = 0.74), whereas high school females ($M$ = 5.20 Hz, $SD$ = 0.82) had faster vibrato rates than high school males ($M$ = 4.94 Hz, $SD$ = 0.78). Figure 3 on the next page shows the interaction. A two-way interaction also occurred between participant experience and vibrato condition of models, $F(1, 72) = 12.67$, $p = .001$, $\eta_p^2 = .15$. High schoolers responded to both vibrato conditions with similar vibrato rates (vibrato $M$ = 5.11 Hz, $SD$ = 0.62; min vibrato $M$ = 5.03 Hz,

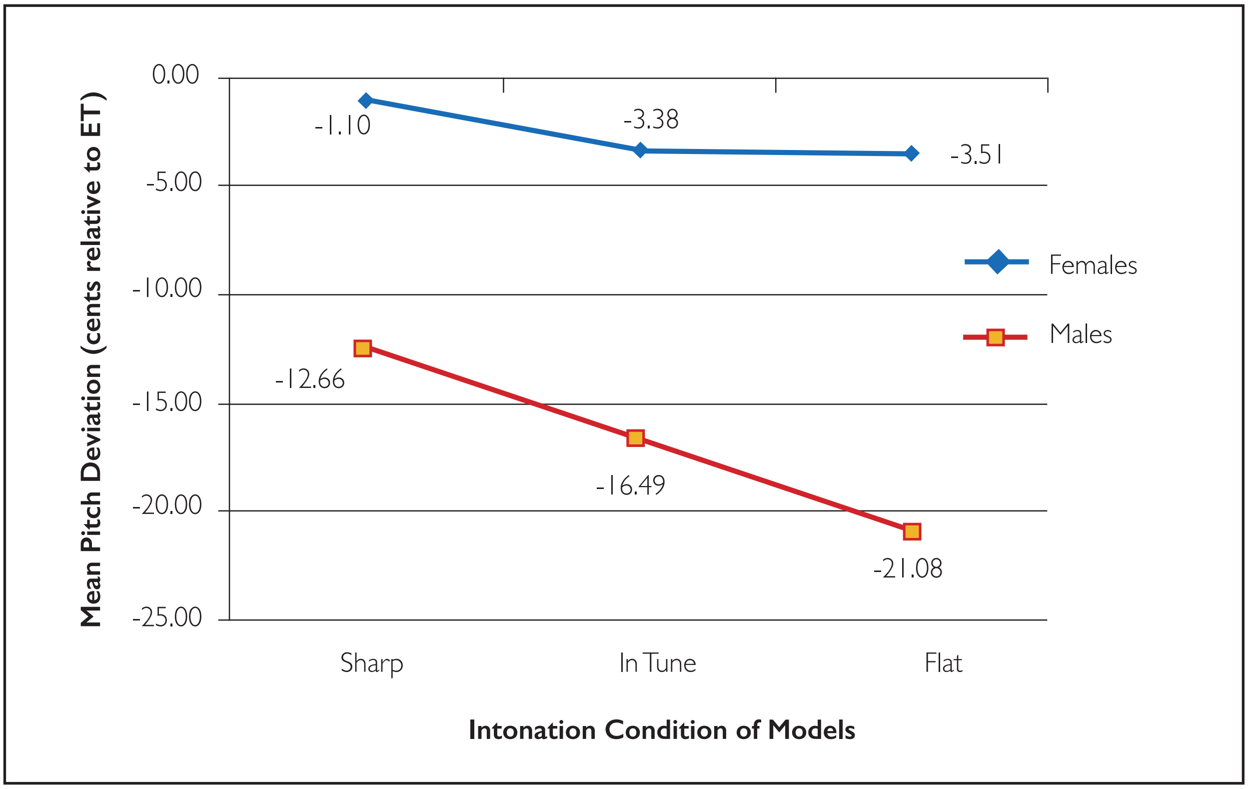


**Figure 2**

*Interaction of participant gender and intonation condition on mean pitch deviation.*

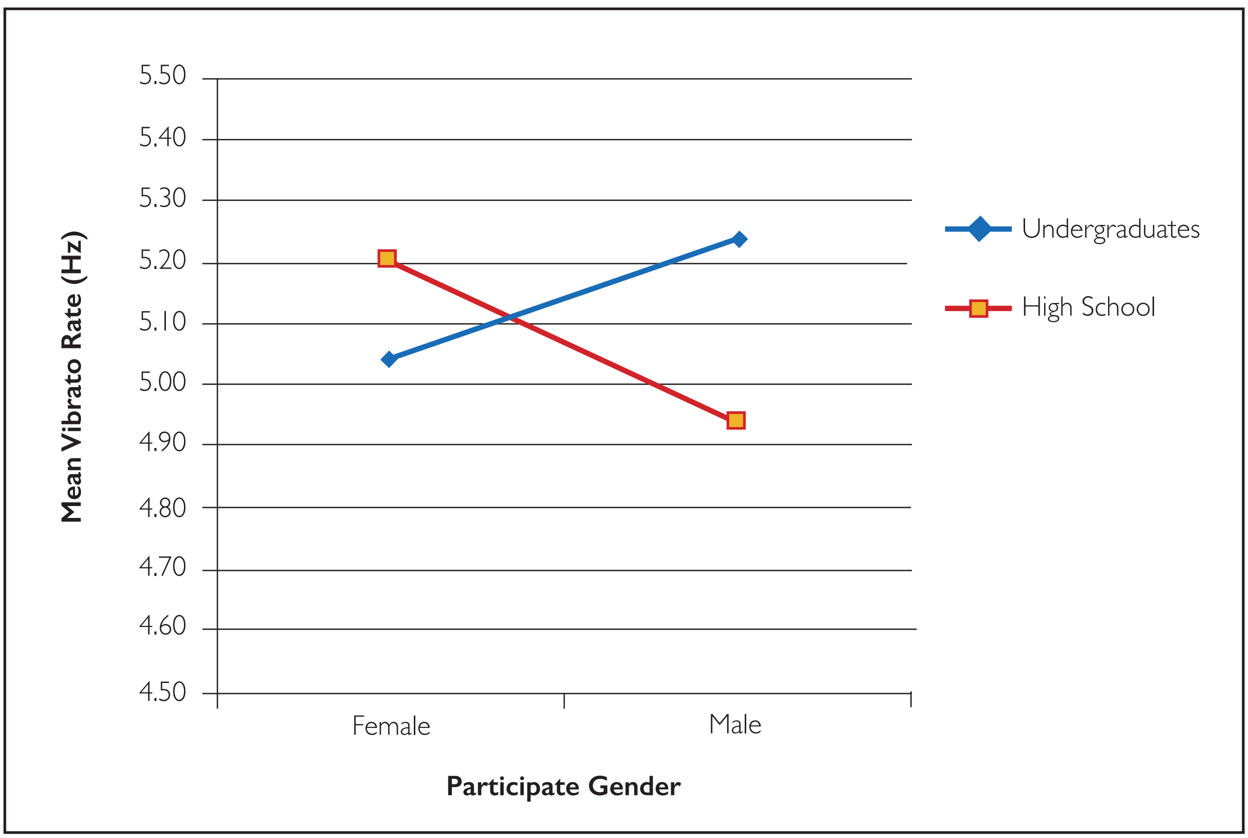


**Figure 3**

*Interaction of participant gender and experience on mean vibrato rate.*

*SD* = 0.58), while undergraduates responded with faster vibrato rates to vibrato models (*M* = 5.32 Hz, *SD* = 0.60) than to minimal vibrato models (*M* = 4.96 Hz, *SD* = 0.54). Figure 4 displays the interaction.

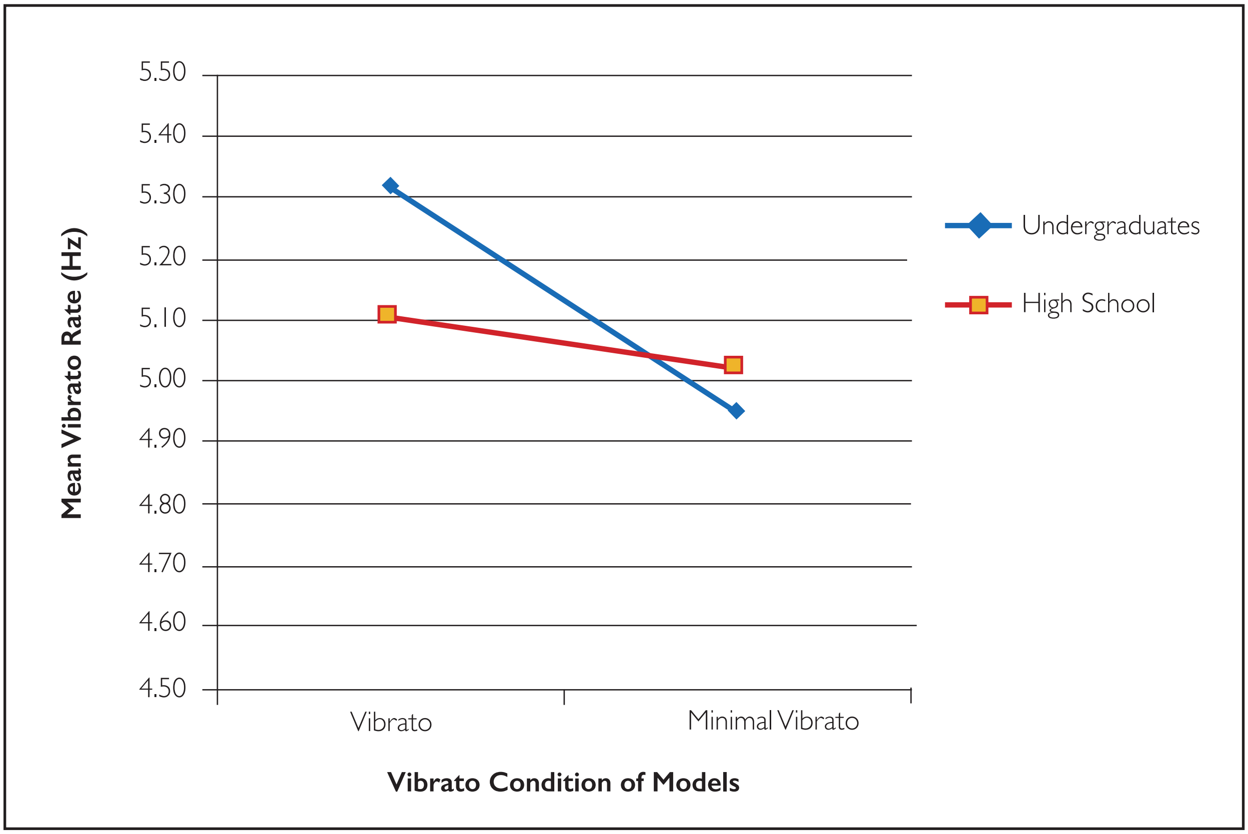


**Figure 4**
*Interaction of participant experience and vibrato condition on mean vibrato rate.*

## Research Question Three: Vibrato Extent

Raw data consisted of vibrato extent analysis of individual pitches, as measured by the average distance in cents between peaks and troughs of vibrato cycles. I observed a main effect for the vibrato condition of models, $F(1, 72) = 54.23$, $p < .001$, $\eta_p^2 = .43$, as participants sang with wider vibrato extent in response to vibrato models (*M* = 81.46 cents, *SD* = 29.46) than to minimal vibrato models (*M* = 59.31 cents, *SD* = 25.36). I also observed a main effect for participant experience, $F(1, 72) = 7.94$, $p = .006$, $\eta_p^2 = .09$, as undergraduates (*M* = 78.22 cents, *SD* = 33.30) sang with wider extent than high school participants (*M* = 62.55 cents, *SD* = 35.13). As with vibrato rate, a two-way interaction occurred between participant experience and the vibrato condition of models, $F(1, 72) = 23.90$, $p < .001$, $\eta_p^2 = .24$. High schoolers responded with similar extent to vibrato (*M* = 66.27 cents, *SD* = 42.81) and minimal vibrato models (*M* = 58.83 cents, *SD* = 36.89), whereas undergraduates showed greater differences between responses (vibrato *M* = 96.64 cents, *SD* = 40.61; min vibrato models *M* = 59.79 cents, *SD* = 35.00). Figure 5 on the next page shows the interaction.

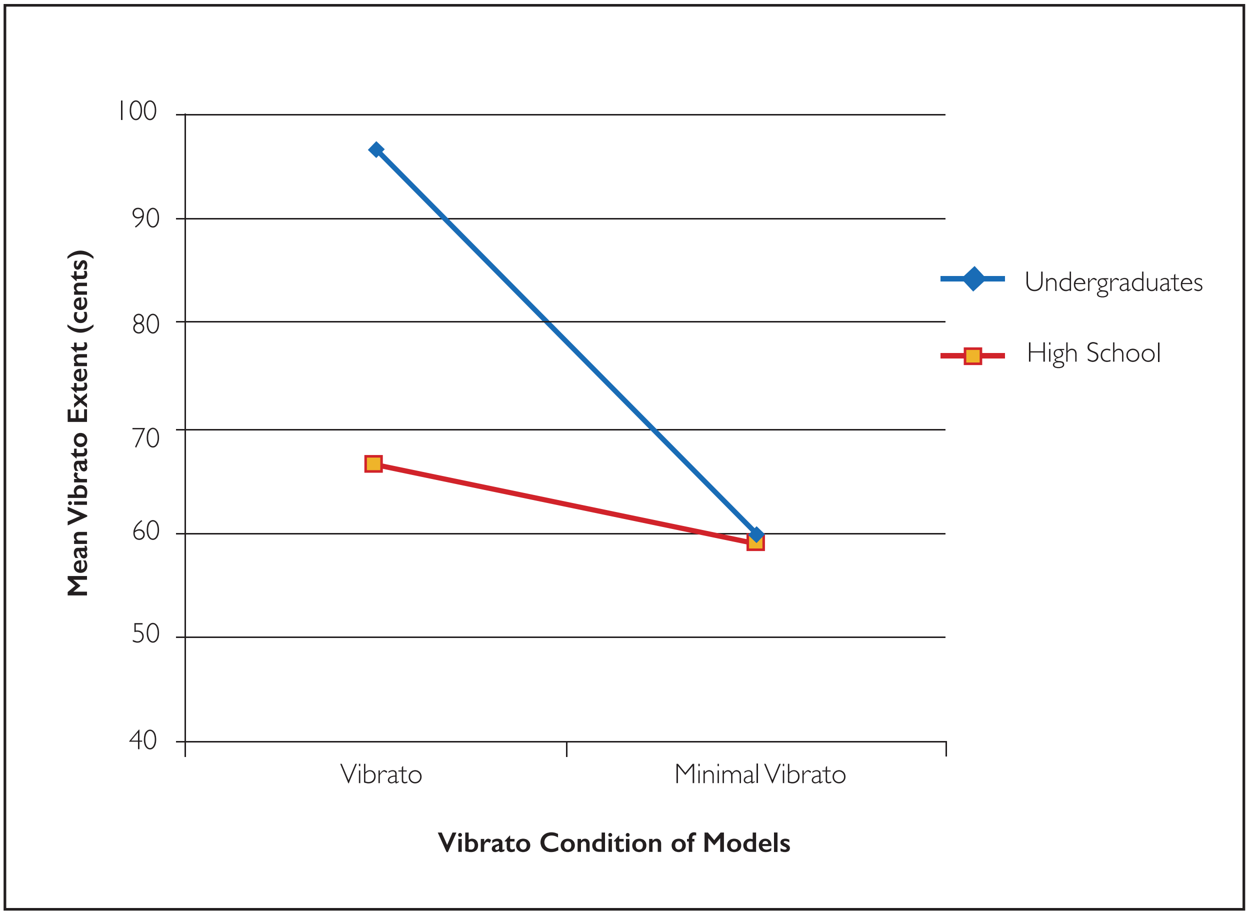


**Figure 5**
*Interaction of participant experience and vibrato condition on mean vibrato extent*

### Research Question Four: Perception of Differences in Vocal Models

Of the 76 total participants, 71 singers (undergraduates *n* = 39, high schoolers *n* = 32; males *n* = 36, females *n* = 35) indicated on the post-stimuli questionnaire they perceived differences between models. My analysis of written responses showed the most frequently used keyword(s) to be *vibrato/straight tone* (*n* = 36), followed by *timbre/tone quality* (*n* = 13), and *intonation/pitch* (*n* = 12). Undergraduates perceived changes in vibrato (*n* = 25) and intonation (*n* = 8) more often than high school participants (vibrato *n* = 11; intonation *n* = 4). Male participants noticed changes in timbre/tone quality (*n* = 10) and intonation/pitch (*n* = 8) more often than females (timbre/tone quality *n* = 3; intonation/pitch *n* = 4), whereas changes in vibrato were more often perceived by females (*n* = 22) than males (*n* = 14).

## Discussion

This study investigated the effects of vibrato and pitch-varied vocal models on acoustic measures of high school and undergraduate singers' vocal performance, with singers' perception observed as a secondary purpose of research. Primary findings of this study suggest that pitch-varied models may affect singers' pitch accuracy, whereas vibrato-varied models may produce differences in vibrato and intonation. All singers displayed a propensity towards flat singing, with male participants singing overall more flat than female participants. Participants responded with the greatest pitch deviation to flat models and the least deviation to sharp models. Responses to vibrato models were more in tune than responses to minimal vibrato models, with faster vibrato rate and wider extent. Perception responses on the post-stimuli questionnaire indicated that singers more readily perceived differences in vibrato than in intonation.

One rationale to account for differences in response to mistuned models (flat models $M$ = -12.30 cents; sharp models $M$ = -6.88 cents) may be relative to participants' perception. As musicians demonstrated a greater tolerance for sharp intonation (Geringer & Witt, 1985; Morrison, 2000), it is possible that singers were more cognizant of flat models which therefore produced greater pitch deviation in responses. Singers' general propensity towards flat singing may have also compounded their greater response to flat models. Other contributing factors towards flatness may have been the morning testing time for high schoolers and differences in vocal warm-up time between singers. As total testing time was 10 minutes, it is also possible that singers experienced vocal fatigue and/or lack of focus during the process. Future researchers examining singers' pitch accuracy response to mistuned models might consider testing all participants in the afternoon, using a standardized warm-up with a shorter testing process.

Responses to pitch-varied models also showed that males displayed a greater inclination towards flat singing (male $M$ = -16.75 cents; female $M$ = -2.66 cents). These results may have been due to the male changing voice, although the range of the vocal models and early hour in which high schoolers tested may have also influenced male singers' intonation. Further, informal observations of sound levels during the recording process noted that males sang with similar amplitude on most pitches, regardless of range. While limited, this information suggests that males' reduced amplitude on higher pitches may have contributed to flat singing. To further investigate this theory, future researchers might explore a potential relationship between singers' sound levels and intonation, particularly with male changing voices.

Responses to vibrato-varied models (min vibrato $M$ = -11.80 cents; vibrato $M$ = -7.61 cents) suggest that high school and undergraduate singers may sing more out of tune in response to minimal vibrato models. Results in the current study are inconsistent with prior research (Duvvuru & Erickson, 2016), in which vibrato-varied models produced no pitch accuracy differences with undergraduate and professional female singers. Such differences may be due in part to training, gender, and singing tasks. Duvvuru and Erickson (2016) asked singers to match single pitches in response to vibrato-varied models, a short task that well-trained female singers were likely able to execute with accurate intonation. Less trained male and female singers in the current study imitated a pattern and song excerpt in vibrato-varied conditions, longer tasks which may have been more difficult to maintain with minimal vibrato, particularly those with male changing voices. This theory is only speculation however, as it is unknown how much instruction participants received on vibrato prior to either study.

The observed effects of vibrato-varied models may have also been unique to the design of this study, as analysis occurred on only two pitches in each model response. Further, it is possible that the acoustic analysis methodology used in this study was not fully reliable in measuring pitch accuracy with complex vibrato sounds (Larrouy-Maestri, et al., 2013; Larrouy-Maestri et al., 2014a; 2014b). Analysis of some responses may be valid however, as participants widely varied in their use of vibrato. Future researchers in model studies with vibrato singing might consider using a different tuning standard as a referent for analysis (Larrouy-Maestri et al., 2014b). As Howard (2007) observed that singers in *a capella* choirs tended towards just tuning, perhaps use of this temperament might provide a more objective analysis of unaccompanied vibrato singing.

Results of the current study suggest vibrato models may elicit faster vibrato rate (vibrato $M = 5.22$ Hz; min vibrato $M = 4.99$ Hz) and wider extent (vibrato $M = 81.46$ cents; min vibrato $M = 59.31$ cents). As singers in previous studies were able to modify vibrato rate in an attempt to match target stimuli (Dromey et al., 2003; Titze, et al., 2002), participants in the current study also demonstrated the ability perceive differences in vibrato and make adjustments. Further, Titze et al. (2002) maintained that vibrato extent was more controllable than vibrato rate, findings also consistent in the current study. Considering that instructions to participants were to imitate vocal models as if in response to their choral conductor, adjustments were likely intentional on the part of at least some singers. This explanation is further plausible since 51% of participants indicated they perceived vibrato differences between models. As adjustments were not consistent in response to vibrato-varied models, conductors might consider increasing verbal specificity when referring to vibrato, should they desire a more uniform response from singers (Mann, 2014). To further investigate this premise, future researchers might compare the effects of vocal modeling with and without verbal prompts on singers' use of vibrato. Such research may show if singers are changing consciously or subconsciously in response to stimuli and if modeling could potentially replace verbal instruction.

As differences in vibrato occurred between participant groups, these results suggest singers' experience may influence vibrato characteristics. High school participants responded to vibrato-varied models with similar vibrato rate (vibrato $M = 5.11$ Hz; min vibrato $M = 5.03$ Hz) and extent (vibrato $M = 66.27$ cents; min vibrato $M = 58.83$ cents), whereas undergraduates displayed greater differences in rate (vibrato $M = 5.32$ Hz; min vibrato $M = 4.96$ Hz) and extent (vibrato $M = 96.64$ cents; min vibrato $M = 59.79$ cents) between vibrato-varied conditions. These differences may be a result of formal instruction, as researchers have found that training increased vibrato rate and widened vibrato extent (Mitchell & Kenny, 2010; Mürbe et al., 2007). Future investigators might continue to explore the effects of vibrato-varied models on less trained singers.

This research also explored singers' perceptions of vocal models to investigate a potential relationship between perception and production. Participants' perception of changes in vibrato (51%) and intonation (15%) somewhat showed in vocal responses, as vibrato-varied models produced differences in all dependent measures, whereas mistuned models only affected intonation. While researchers observed that musicians' optimal pitch discrimination threshold was 4 - 6 cents in the middle octaves (Spiegel & Watson, 1984), vibrato conditions may have masked participants' perception of mistuned models in this study (Geringer, MacLeod, Madsen, & Nápoles, 2015; Geringer, MacLeod, & Sasanfar, 2015). Another potential reason for singers' lack of perception of mistuned models may have been because pitch-varied conditions only affected two notes per vocal model, unlike the vibrato conditions imposed throughout.

While perception and production do not have a clear relationship in this study, it is notable that differences in singers' vibrato and intonation were still present in responses. As researchers found that focus of attention influenced perception and listening patterns (Madsen & Geringer, 2000/2001), singers may have responded differently if directed to listen for changes in intonation and/or vibrato. Future researchers might investigate the concurrent effects of vocal modeling and focus of attention on singers' vocal performance.

## Teaching Implications and Limitations

Given singers' responses to mistuned models in the present study, choral educators might try to be more accurate in their modeling, particularly in an attempt to avoid flat singing. Conductors might also consider pairing a verbal prompt with a vocal model to direct singers' ears towards nuances in intonation, especially when vibrato is present. As researchers observed that self-analysis through video reflection changed teaching practices (Nápoles & Vázquez-Ramos, 2013), choral educators may benefit from video recording rehearsals to observe modeling tendencies and improve singing accuracy. One of the most salient observations in this study was that pitch-varied models affected singers' accuracy, mistunings of which many participants did not perceive. Choral educators may need to acknowledge the possibility that singers regularly imitate vocal inaccuracies, imprecisions of which the conductor and/or singer may not be cognizant of in the moment. Consequently, consistent self-assessment through video analysis may be the key to increasing choral educators' awareness and improving modeling practices.

As responses to vibrato models in this study showed an increase in vibrato rate and extent, particularly with more experienced singers, choral educators might consider modeling with less vibrato if an overall reduction in vibrato is desired. If preference is for less vibrato, however, conductors may need to teach singers how to make vocal adjustments that are accurate in pitch, but free of vocal tension. Consulting expert voice teachers in this process is highly recommended to better understand the physiology involved in these adjustments.

While the purpose of this research was to explore vocal modeling for use within a choral setting, participants responded individually to vocal models and on a neutral syllable rather than on choral text. Participants also tested at different times of the day, with varied times spent in vocal warm-ups. Further, while the re-analysis of 20% of responses yielded high reliability, the use of outside raters may have provided differing analyses. The acoustic analysis methodology used in this study may not have been fully reliable for those singers responding with complex vibrato sounds. Given these limitations, it is impractical to generalize results to all high school and undergraduate choral settings.

## Conclusion

Many complex factors appear to contribute to the results of this study, including perception, formal training, vocal development, and vocal production. Results suggest that out of tune models may affect singers' intonation and that singers may imitate nuances in pitch, regardless of perceptions. Trained singers seem to imitate differences in vibrato more so than less experienced singers, possibly because of increased perception and formal training. Choral educators should consider the use of video self-analysis to both increase awareness of modeling tendencies and to improve singing accuracy. While Dickey (1992) observed modeling to be an effective strategy for music educators at all levels, the current study did not fully explain the effects of vibrato or pitch-varied vocal models. Continued research may help better understand how choral educators can consistently use vocal modeling as an effective teaching strategy.

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