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The Effects of Emotion on Acoustic Characteristics of Vocal Vibrato in Trained Singers

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ABSTRACT

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The purpose of this study was to investigate the effects of emotion on several key acoustic features of vibrato including vibrato rate, extent, and steadiness (measured by FM rate COV and FM extent COV). We hypothesized that intensity of emotion would have a significant effect on vibrato rate, extent, and periodicity, although the direction of these changes was undetermined. There were 10 participants, including eight females and two males, who were graduate student singers with high competency ratings. Each participant completed a series of tasks including sustained vowels at several pitch and loudness levels, an assigned song that was determined to have neutral emotion, and a personal selection that was selected because it included sections of intense emotion. Vowel tokens were averaged for each task, and measurements of mean f0, mean dB, FM rate, FM extent, FM rate COV and FM extent COV were calculated by task for each participant. Contrast analyses were performed comparing each task against the personal selection (high emotion) task. The results suggest that FM rate and FM rate COV may have been influenced by level of emotion, and FM extent, FM rate COV and FM extent COV were likely influenced by the performance nature of the task.

Keywords: vibrato, emotion, vibrato extent, vibrato rate, FM rate, FM extent

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Description of Structure and Content

This thesis is presented in a hybrid format where current journal publication formatting is blended with traditional thesis requirements. The introductory pages are therefore a reflection of the most up to date university requirements while the thesis report reflects current length and style standards for research published in peer reviewed journals for communication disorders. Appendix A is composed of an annotated bibliography. Appendix B includes the informed consent form for the singers.

Introduction

Vocal Vibrato

The characteristics of vocal vibrato have been studied for many years. C.E. Seashore pioneered the use of acoustic measures to examine vocal vibrato as early as the 1930s. Seashore (1931) defined vibrato as "a periodic pulsation, generally involving pitch, intensity, and timbre, which produces a pleasing flexibility, mellowness, and richness of tone" (p. 623). Vocal vibrato is understood to be a natural occurrence in a well-balanced singing voice (Ekholm, Papagiannis, & Chagnon, 1998), and is seen as one of the means a singer may use to portray emotion (Howes, 2004; Seashore, 1931).

Several acoustic features of vibrato have been studied in detail since Seashore made his first observations, including the rate, extent, and periodicity of the vocal modulations (Corso & Lewis, 1950; Ferrante, 2011; Howes, 2004). Vibrato rate is defined as the number of fundamental frequency (F_0) and amplitude pulses per second (Seashore, 1931). Frequency modulation (FM) and amplitude modulation (AM) both contribute to vibrato rate. AM is largely an epiphenomenon that arises from the resonance-harmonic interaction (RHI; Horii, 1989; Horii, 1988). The RHI is the interaction between rising and falling harmonic frequencies, as a result of fluctuating F_0, and the formant peaks in the vocal tract transfer function that determine the overall intensity of a sound. This interaction creates an involuntary modulation in amplitude with the modulation in F_0 (Horii, 1989; Horii, 1988). It is important to note that there is also a laryngeal component of AM that can be measured through electroglottography (Dromey, Reese, & Hopkin, 2009), although this study will not examine AM, because the target behavior for a singer is the modulation of fundamental frequency.

The rate of vocal vibrato is not hard-wired in the brain, as it can be modified by the singer with conscious effort; however, singers have a natural speed of vibrato, and rate can only be changed modestly with volitional control (Dromey, Carter, & Hopkin, 2003). The average rate of vibrato has been reported within the 5-7 Hz range (Corso & Lewis, 1950; Howes, 2004; Seashore, 1931), with fluctuation relating to the location within a musical passage (Prame, 1994), or amount of vocal training (Brown, Rothman, & Sapienza, 2000; Mendes, Rothman, Sapienza, & Brown, 2003; Mitchell & Kenny, 2010; Murbe, Zahnert, Kuhlisch, & Sundberg, 2007). Prame's (1994) research showed that vibrato rate may not remain the same throughout a sustained note, and that the location of a tone within a musical piece may have an effect on the vibrato rate. Several studies have also shown that with vocal training, vibrato preferences and vibrato characteristics of an individual singer change (Ferrante, 2011; Mitchell, 2010). More specifically, vibrato rate tends to become more consistent for those who are originally inconsistent. Inexperienced singers with an exceptionally fast rate tend to decrease rate to a more average pace with training, and singers with an originally slow rate tend to increase rate to a more average pace with training. (Mitchell & Kenny, 2010; Murbe, Zahnert, Kuhlisch, & Sundberg, 2007).

As defined by Seashore (1931), vibrato extent is the distance between the crest and trough of the F_0 trace, and is measured in semitones (ST), or fractions of a tone. The average extent of vibrato is reported between .41 and 1.58 ST (Howes, 2004). Vibrato extent has generally increased over the course of the past century (Ferrante, 2011), and it also increases in individual singers after a significant period of vocal training (Mitchell & Kenny, 2010). Although much has been revealed regarding the role of extent in the overall function and beauty of vibrato, much is left to be discovered, including the effects of emotion on vibrato extent.

Vibrato and Vocal Beauty

The quest to acoustically identify a beautiful voice has occupied researchers for a number of years. The suggestion of a specific set of acoustic and physical characteristics as being the keys to a pleasing vocal sound may seem simple on the surface, but many factors are involved in beautiful singing. Among the most commonly cited contributions is vibrato.

Robison, Bounous, and Bailey (1994) compared vocal ratings from an expert judge panel to several acoustic parameters of vocal performance. Singers with the highest ratings of vocal beauty were those with the highest proportion of vibrato per total singing time. Other predictors of vocal beauty included cleanness of voice and adequate breath management. In another study, excessive amplitude modulation, delayed onset of vibrato, and complete absence of vibrato all had negative effects on vocal evaluation (Ekholm, 1998; Howes, 2004). A moderate vibrato rate and extent are also important for professional singers, and a balance in rate and extent facilitates vocal beauty (Ekholm, 1998; Robison et al., 1994). Rothman (2003) concluded that extent was an important aspect of vibrato, one that was reflective of overall vocal quality. He suggested that periodicity of vibrato was also among the most significant indicators of vocal beauty.

While this is only a short list of characteristics, it is part of a body of research that continues to uncover the vocal qualities we consider most beautiful. As singers receive training, these vocal qualities are fine-tuned to bring them closer to a pleasant, balanced voice.

Emotion and Performance

A number of disciplines have established a relationship between emotion and performance. In the world of sport psychology, the presence of positive or negative emotions during an event has been found to have an effect on the outcome of an athlete's performance (Ruiz, 2008). In one study, the athletes' specific physical task, their level of emotion and type of emotion (excitement, nervousness, anger, etc.) at the time of performance all contributed to the outcome of their performance. Some athletes used a positive emotion, and some used a negative emotion as motivation while executing the physical task. The findings suggested that positive emotions and negative emotions led to marginally different outcomes when compared against each other; however, the presence of any motivating emotion, positive or negative, consistently altered the outcome of performance when compared to those who performed the task without the use of a motivating emotion (Ruiz, 2008).

In the world of theater, the ability to assume the role of a character while portraying real emotion is a vital skill. An actor is both himself and a nonexistent character at once. This duality of an actor on stage is an essential element of theater. The duty of an actor is to make what is artificial seem genuine, and evoke an emotion in the audience that is not necessarily felt by the actor, but by the character. 'Emotion memory' is a method that teaches actors to simulate emotion in the present by recreating in their mind the circumstances of a specific past event that brought about the same emotions. This technique helps actors create real emotion from what is otherwise an invented feeling, as they sort through personal and character emotions in attempt to convince the audience of what the character is feeling (Harrop, 1992).

Findings from several fields of performance can be related to music as well. Musical opera contains elements of spoken theater, with each singer acting on behalf of a character, telling a story through spoken language and through song. Emotion is a key ingredient to a successful and persuasive vocal performance. Baltes, Avram, Miclea, and Miu (2011) found that experiencing music through listening, watching, and learning the plot of an opera led to physiologic changes in a viewer. It could likewise be hypothesized that emotions of a piece of music bring physiologic changes to the performer. If this is the case, it may be manifest through changes in the characteristics of the performer's vibrato.

Emotion and Voice

In order to understand how emotion is expressed and recognized in a singing voice, it is helpful to have some background in the vocal features that are used to convey and distinguish emotion in everyday speech. Patel et al. (2011) suggested that vocal quality was a crucial element of emotional speech. According to their findings, vocal quality includes the perturbation, frequency, and effort of phonation. In another study, rate, pitch height and intensity were features of both speech and music that helped listeners to decode emotion (Ilie, 2006).

During his early research on vibrato, Seashore briefly addressed emotion as a contributor to vibrato characteristics. At that time it was suggested that vibrato had been found throughout the ages in many cultures, and that it occurred during emotional singing, or singing with feeling. Although Seashore (1931) mentioned an emotional aspect to the appearance of vibrato, there was no clear evidence at that time that emotion had a direct effect on the characteristics of vibrato. Few studies have been conducted that show the effects of emotion on specific qualities of vibrato. Howes (2004) found that judges were able to correctly identify the emotion of a singer during a short cadenza, which confirms that the singers were able to effectively portray the target emotion. This still does not explain the effect of the singers' emotion on the acoustic features of their vibrato.

The purpose of this study is to investigate the effects of emotion on several key acoustic features of vibrato. We hypothesize that intensity of emotion will have a significant effect on vibrato rate, extent, and periodicity, although the direction of these changes has yet to be determined. The results of this study may yield insights about singing physiology and the mechanics of modifying vibrato. This study may help professionally trained singers in their quest for vocal beauty by shedding light on the connection between the expression of emotion and a balanced vibrato.

Method

Participants

Ten graduate student singers with high vocal competency ratings from the BYU School of Music participated in this study. All singers were rated between 3.0 and 4.05 on a scale of 1.0 to 5.0 for vocal technique. All singers were trained in the Western classical style of music. The mean age of the singers was 23.9, years (*SD* = 2.08). Eight were women and two were men. All ten participants reported good health and denied a history of hearing or voice disorders. The experimenters also listened to each participant's voice and found it to be perceptually within normal limits. Each participant signed a consent form that was approved by the university's institutional review board.

Equipment

Recordings of the participants were made in BYU's Studio Y, a professional sound studio. Before each day of recordings began, a sound level meter (Extech Instruments 407736) was positioned 50 cm from the microphone to calibrate vocal intensity. A Neumann TLM 49 condenser microphone was placed inside a sound isolation shell, with the pickup pattern of the microphone facing away from the piano to reduce signal bleed. An Audient 8024 Analog Recording Console, Grace Model 201 2-Channel Preamplifier, and ProTools 10 HD2 Recording System were used for the recordings.

Procedure

Each participant was recorded once in the studio, having been asked to perform individually chosen warm-up exercises before beginning the recording session. An accompanist was provided for the recordings of all participants. The following tasks were performed by each singer in randomized order to minimize the likelihood of an order effect.

Personal selection. Each participant was asked to sing a song they had been practicing with their vocal instructor. At the time of recruitment, each singer was encouraged to be expressive with the emotion of their selection, and each selection should have sections of both high and low levels of emotion. At the time of recording, no instruction regarding emotion was given. Participants were asked to supply a copy of their musical selection with annotations to indicate the performer's rating of the emotional level of each part of the song. Participants rated sections of their selection on a scale of 1 to 5, 1 being a section of relatively neutral or low emotion, and 5 being a section of their highest or most intense emotion. These ratings were used during signal analysis to extract segments of highest emotion.

Assigned song. Each singer was asked to sing the first 12 measures of the song "Caro mio ben" by Giordanni, which was chosen by Dr. Arden Hopkin of the BYU School of Music as a song with neutral emotion and prolonged vowels suitable for analysis. This short song was sung once at a self-determined comfortable pitch and intensity.

Sustained vowels. Each participant was asked to sing isolated vowels /ɑ/, /u/, and /i/ along pitch and loudness continua. The participant sang each vowel at a comfortable pitch, with three different intensities: low, medium, and high. The participant was also asked to sing each vowel at a comfortable intensity, with three different pitches: low, medium, and high. Tasks within the sustained vowel section were also randomized in order to minimize the likelihood of an order effect.

Data Analysis

Digital recordings from Studio Y were transferred to a lab computer for analysis. The files were first segmented to extract isolated vowel tokens from the singing passages as individual 44.1 kHz wav files. These vowel tokens were opened with Praat acoustic analysis software (version 5.3.03) to generate a f0 contour, which was exported as a text file with values reported at 1 ms intervals. These audio files were also analyzed with custom Matlab software (MathWorks, 2009b) to create an RMS contour, also at 1 ms sample intervals. Acoustic measurements were derived from the recordings with a custom Matlab application, to compute variables reflecting vibrato rate, extent, and steadiness, as well as means of f0 and intensity.

During vowel segmentation, the individual tokens were trimmed minimally, leaving the longest duration possible for each vowel; therefore, vowel tokens varied in length across all tasks. Instances of delayed onset of vibrato were also included in the analysis. Vowel tokens were excluded from analysis when the piano intensity overcame the acoustic shielding and affected the voice recording to the extent that the analysis yielded a visibly contaminated f0 trace.

Independent variables. The independent variables will be defined individually below.

Personal selection (PS). The personal selection was assumed to involve the highest level of emotion among the tasks. This was the task of primary interest, and therefore during statistical analysis the dependent measures for the other conditions were compared to this one to evaluate changes attributable to emotion. The personal selection was considered to be a performance task, meaning it was most representative of singing in a concert, because the participant sang an entire song.

Assigned song (CMB). "Caro mio ben" was considered an emotionally neutral song when compared to the personal selection. This song was assumed to involve neutral emotion because it is often used as a warm-up song, with the singers' main focus on technique. This selection, however, was considered a performance task along with the personal selection because the participant sang multiple phrases within the context of a familiar song.

Sustained vowels across pitch conditions. Within the sustained vowel task, the singers produced vowels at a comfortable vocal intensity while changing pitch. The participants sang a self-determined low pitch, comfortable pitch, and high pitch, each at a comfortable intensity. These tasks were assumed to have the most neutral emotion, and were also considered isolated phonation tasks, meaning they had no real context and they were the least representative of a concert performance.

Sustained vowels across loudness conditions. Within the sustained vowel task, the singers produced vowels at a comfortable pitch while changing their vocal intensity. The participants sang at a self-determined low loudness, comfortable loudness, and high loudness. As with the pitch continuum, these tasks were also assumed to have the most neutral emotion as isolated phonation tasks.

Personal selection vowel tokens were chosen from the sections of highest emotion, as rated by the singers on their music score. The dependent measures from the first 20 high-emotion vowel tokens from each singer were averaged to create the personal selection data set. The assigned song data set was created from the same five vowels for each participant. These vowels were chosen for their length, providing vowel tokens with comparable duration to those from the personal selection. Pitch and loudness summary values of the dependent measures were generated by averaging data from all /ɑ/, /u/, and /i/ vowels for each condition, because initial analysis revealed no differences between the three places of articulation.

Dependent measures. Figure 1 illustrates how the dependent variables were defined.

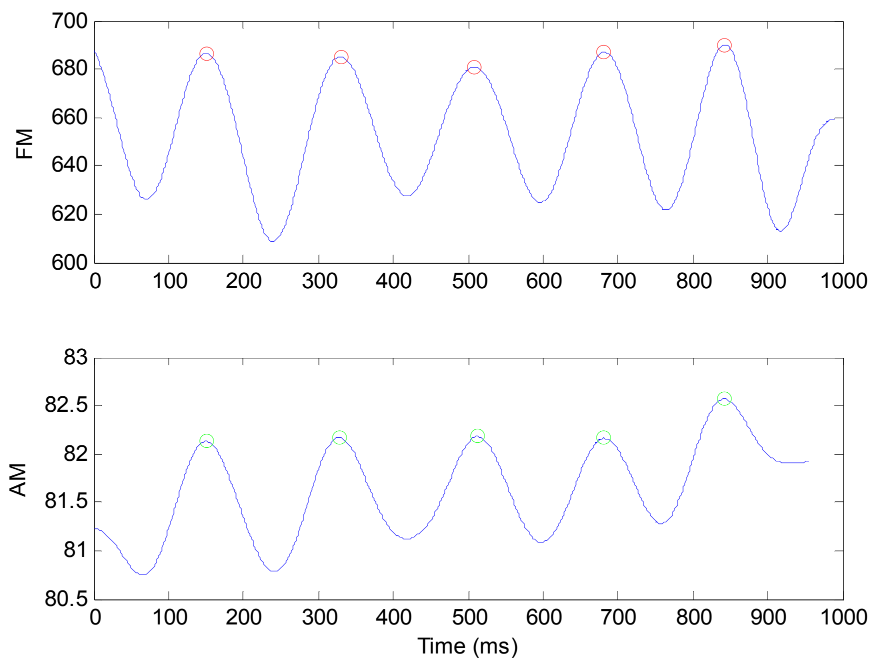

Figure 1. FM and AM traces for an individual vowel token, with software-derived peak markers which were used to calculate FM rate, FM extent, FM rate COV and FM extent COV.

Mean f0. The mean f0 was measured in Hz. This was the average fundamental frequency during each vowel token.

Mean intensity (dB). The intensity mean was measured in dB SPL. This variable was calculated as the average intensity during each vowel token.

FM rate. FM rate was measured in Hertz (Hz), and was calculated through the use of a peak- and trough-picking algorithm that identified the temporal location of each FM cycle. The rate was computed as the inverse of the mean period of each cycle.

FM extent. FM extent was measured in semitones (ST). This was calculated by taking the maximum value (peak) minus the minimum value (trough), averaged over all cycles.

FM rate COV. This variable was a measure of the regularity of the FM rate. It was computed by dividing the standard deviation by the mean of the FM period of a vowel token, which was then multiplied by 100 to make the numbers more convenient to interpret.

FM extent COV. This variable was a measure of the regularity of the FM extent. It was computed by dividing the standard deviation by the mean of the FM extent for the modulation cycles within a vowel token, which was then multiplied by 100 to make the numbers more convenient to interpret.

Statistical Analysis

Univariate repeated-measures ANOVA tests were used to evaluate the statistical significance of changes in the dependent measures of vibrato across the vocal task conditions of the independent variable. An initial analysis of the vowels /ɑ/, /u/ and /i/ showed no significant differences in the dependent measures. Because the data were comparable for all vowels, they were therefore averaged for each pitch and loudness level before further analysis. Contrast tests within the ANOVA model compared the task with the highest level of emotion (the personal selection) with each of the other tasks.

Results

Figure 2 and Figure 3 show mean and standard deviation comparisons for pitch (Figure 2) and loudness (Figure 3) continua graphically. The assigned song and personal selection are also presented for comparison with the sustained vowel tasks. Table 1 and Table 2 show the F-ratios and P-values for each of the statistically significant findings for pitch and loudness continua respectively.

Table 1

Inferential Statistics for the Dependent Measures in the Pitch Continuum, Including Main Effect and Contrast Analyses Against the Personal Selection Task.

	Main Effect		Low Pitch		Comf Pitch		High Pitch		CMB	
Variable	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
FM rate	5.475	.002	26.336	.001	29.263	.000	13.183	.005		
FM extent	28.238	.000	53.030	.000	45.933	.000	29.436	.000		
FM jitter	8.043	.000	6.453	.032			9.606	.013		
FM shimmer	4.194	.007	6.457	.032			5.133	.050		
Mean f0	54.459	.000	97.604	.000	14.150	.004	14.006	.005	25.928	.001
Mean dB	42.657	.000	81.041	.000	7.225	.025			26.849	.001

Note. CMB= Caro mio ben; Comf= Comfortable.

Table 2

Inferential Statistics for the Dependent Measures in the Loudness Continuum, Including Main Effect and Contrast Analyses Against the Personal Selection Task.

	Main Effect		Low Loud		Comf Loud		High Loud		CMB	
Variable	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
FM rate	8.708	.001	17.053	.003	31.840	.000	54.636	.000		
FM extent	33.408	.000	35.545	.000	21.124	.001	30.134	.000		
FM jitter	7.200	.000								
FM shimmer	3.977	.027	6.542	.031						
Mean f0	15.460	.000	35.470	.000	22.683	.001	22.927	.001	25.928	.001
Mean dB	19.716	.000	63.883	.000	11.522	.008			26.849	.001

Note. CMB= Caro mio ben; Comf= Comfortable.

Mean f0

There was a statistically significant main effect of vocal task on mean f0. For the pitch continuum, Figure 2 shows a clear increase in pitch from low to comfortable and to high pitch tasks, as would be anticipated. The assigned song mean f0 appears between the low and comfortable pitch mean f0s. The personal selection mean f0, however, was between the comfortable and high pitch means. For the levels of the loudness continuum, Figure 3 shows consistency between all tasks with the exception of the personal selection, which has an

Figure 2.

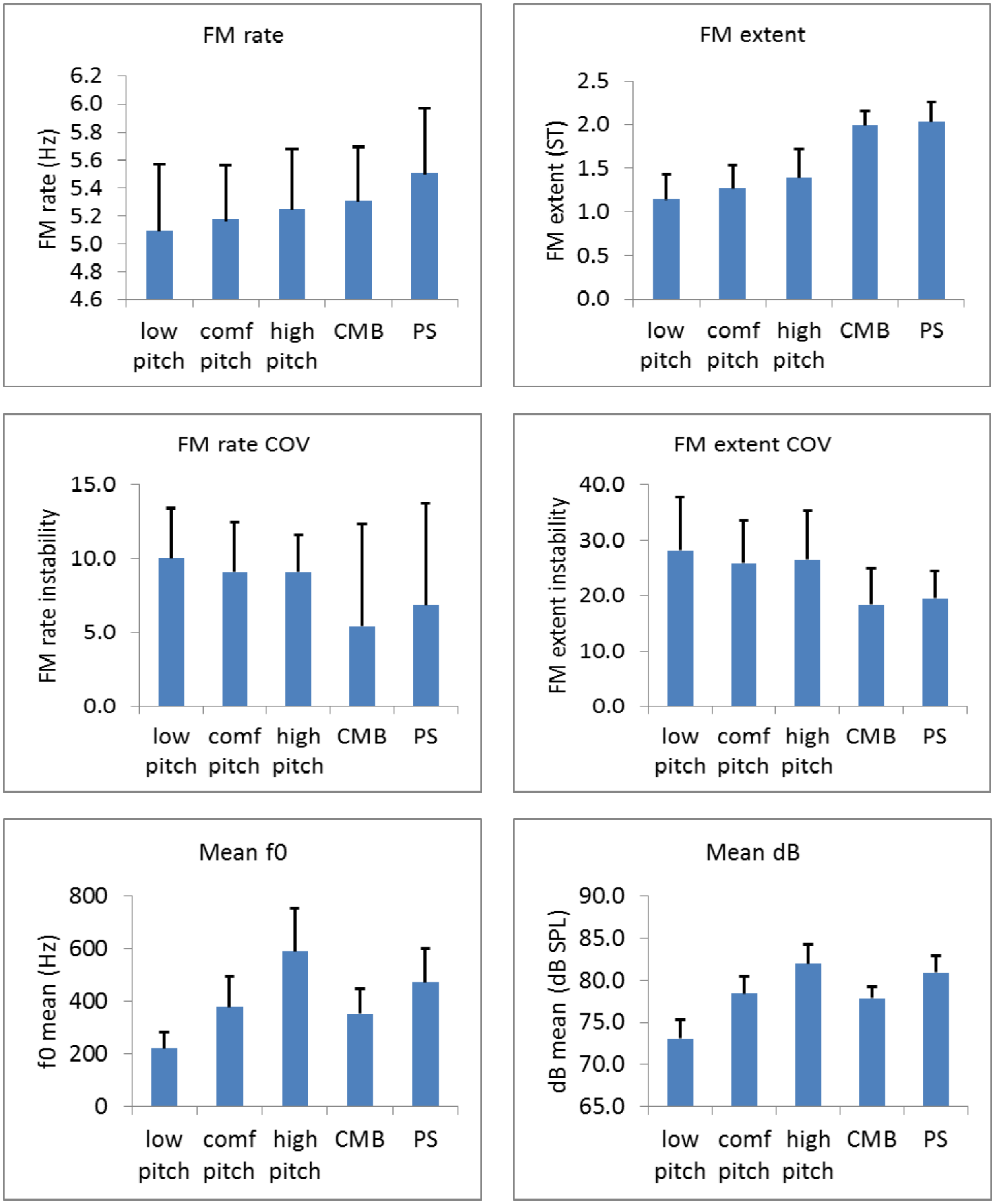

Figure 2. Mean and standard deviation of FM rate, FM extent, FM rate COV, FM extent COV, mean f0 and mean dB across all tasks, within the pitch continuum.

Figure 3.

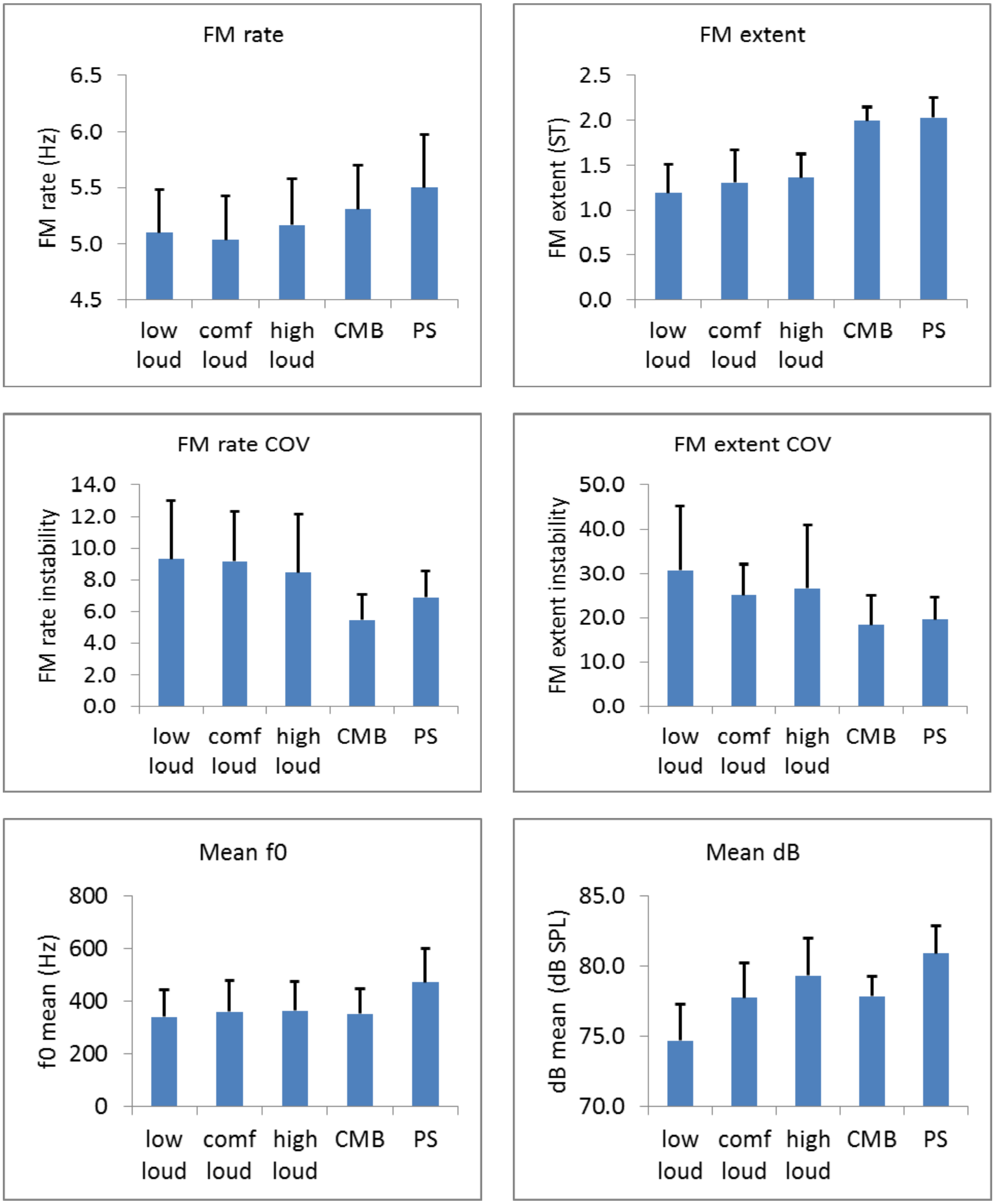

Figure 3. Mean and standard deviation of FM rate, FM extent, FM rate COV, FM extent COV, mean f0 and mean dB for all tasks, within the loudness continuum.

increased mean f0. The contrast analysis confirmed a statistically significant difference between the personal selection and all other tasks (sustained low, comfortable, high, and the assigned song) individually for both the pitch continuum and the loudness continuum.

Mean dB

For both the pitch and loudness continua, there were statistically significant main effects of vocal task on mean dB. A contrast analysis of the pitch continuum revealed that the low pitch and comfortable pitch sustained vowel tasks, as well as the assigned song, had a significantly lower mean dB than the personal selection. The high pitch task, however, showed no significant difference in mean dB from the personal selection. For the loudness continuum, low loudness and comfortable loudness tasks, as well as the assigned song, each were significantly lower in mean dB from the personal selection. The high loudness task showed no significant difference in mean dB compared with the personal selection.

FM rate

There was a significant main effect of vocal task on FM rate of vibrato. Figure 2 and Figure 3 show an upward trend, with FM rate increasing from the neutral emotion tasks to the more emotional task. According to the contrast analysis, no significant differences in FM rate were found between the neutral emotion song and the high emotion song. There were, however, statistically significant increases in FM rate from the sustained vowel tasks to the personal selection in both the pitch and the loudness continua.

FM extent

In both pitch and loudness continua, there was a significant main effect of vocal task on FM extent. Figure 2 shows a general increase from the sustained vowel tasks to both performance tasks: Caro mio ben and the personal selection. Figure 3 shows the same pattern for the loudness continua. A contrast analysis revealed that the FM extent for the personal selection was significantly higher than the sustained vowel low, comfortable and high tasks for both pitch and loudness. The difference between the assigned song and the personal selection was insignificant.

FM rate COV

A significant main effect of vocal task on FM rate COV was found for both pitch and loudness continua. A relative decrease in FM rate inconsistency is notable in Figure 2 and Figure 3. Through the contrast analysis, it was found that in the pitch continuum, low and high pitch tasks were significantly more inconsistent in FM rate than the personal selection; however the comfortable pitch and assigned song tasks yielded no significant difference from the personal selection. In the loudness continuum, only a main effect was found, with no significant differences found between individual tasks.

FM extent COV

The main effect of vocal task on FM extent COV was statistically significant in both the pitch and the loudness continua. Figure 2 shows a decrease in FM extent COV for the performance tasks. Figure 3 shows a similar pattern, with more stability for the comfortable loudness task than other sustained vowel tasks. The contrast analysis showed that in the pitch continuum, low and high pitch vowels were significantly more inconsistent than personal selection vowels. For the loudness continuum, only low loudness vowels were significantly more inconsistent than personal selection vowels.

Discussion

This study was designed to investigate the potential effects of emotion on the acoustic features of vocal vibrato. On the basis of evidence that emotion may affect motor tasks such as speech, athletic performance, theatrical performance and overall voice quality, it was anticipated that increased emotion might cause vocal vibrato to change in rate, extent and/or steadiness, although the specific effect that emotion might have on these features was unknown. The results revealed that there were significant changes in vibrato as a function of vocal task; however, the extent to which the changes were due to the level of emotion remains unclear. The results include two main trends, which were seen in Figure 2 and Figure 3. First, there was a general increase in vibrato FM rate across tasks with presumably increasing emotion. Second, there was an increase in FM extent from the isolated singing tasks to the performance tasks. Further examination of the individual dependent measures led to more detailed speculation about what may have caused these changes.

Discussion by Dependent Variable

The dependent measures will first be discussed individually in order to explain in greater depth the changes in each acoustic measure of vibrato.

Mean f0. Figure 3 shows mean f0 during the sustained vowels that were intentionally held at a comfortable pitch while modifying loudness. The results of this set of tasks indicated that the singers were indeed able to keep pitch steady even with increases in loudness. Mean f0 for the personal selection was higher than for the assigned song in the pitch continuum (Figure 2) and higher than all other conditions in the loudness continuum (Figure 3). When considering the method used to collect and segment the data, it could be speculated that the most emotional expressions in a song comprised the vowels or entire phrases that were naturally higher in pitch. Because the singers identified sections of the musical score representing high and low emotion, and the experimenter selected vowels from the sections of highest emotion, the results necessarily reflected a high mean f0 for these high-emotion vowels.

The assigned song mean f0 was between the low and comfortable pitch tasks, and the personal selection mean f0 was between the comfortable and high pitch tasks. The fundamental frequency of each vowel token was measured in order to examine the possibility that mean f0 might be a causal factor for changes in the dependent measures. In the graphs and statistical analyses, the patterns in mean f0 for each task were compared to patterns in the dependent variables for each task. Figure 2 shows the mean f0 for tasks of the pitch continuum, in which the mean f0 for sustained vowel tasks was intentionally modified. This graph also shows the mean f0 of the assigned song and their personal selection. Because the personal selection and the assigned song were both within the f0 range of the sustained vowel tasks, it appears unlikely that the increases in the dependent variables with high emotion were simply a function of mean f0. If mean f0 for the personal selection or the assigned song had been out of the range of sustained vowel mean f0 for low- to high-pitch tasks, the results in other dependent measures may have simply been a product of increasing fundamental frequency above this range. However, this was not the case, as mean f0 was within the range that the singers produced during sustained vowel tasks for the pitch continuum.

Mean dB. The mean intensity of the vowel tokens was examined in order to determine whether changes in the dependent variables might be attributable to a difference in intensity as opposed to the level of emotion. The general trend was for mean dB to follow mean f0: when there was an increase in mean f0, there was also a comparable increase in mean dB. This finding is consistent with the physiologic explanation that a higher subglottic pressure is needed to overcome the increased resistance of stiffer vocal folds during higher notes (Solomon, Ramanathan, & Makashay, 2007). In Figure 2, the mean dB for the personal selection was higher than all conditions except the high pitch task, including the assigned song. The assigned song was chosen intentionally because it did not express any intense emotions; possibly as a consequence of this, there were few loud or high pitch phrases or notes in the piece. Based on the patterns in the data, there is no convincing indication that mean dB significantly influenced the changes in FM rate or FM extent between the neutral-emotion and high-emotion songs.

FM rate. FM rate is a key component of vocal vibrato. Several studies have shown that the average FM rate of vibrato is approximately 5-7 Hz (Corso & Lewis, 1950; Howes, 2004; Seashore, 1931). The average vibrato rate in this study was in the 5 Hz range, with the slowest vowel tokens around 4 Hz, and the highest reaching approximately 6 Hz. In Figure 2, FM rate steadily increased with each task across the pitch continuum, from low pitch to the personal selection. Figure 3 showed a similar pattern, with the exception of the slight decrease in rate for the comfortable loudness task. Because the pattern in FM rate differed from that of mean f0 across the pitch continuum and mean dB across the loudness continuum, the data suggest that the FM rate of vibrato was potentially influenced by the level of emotion in the task. This inference is supported by the observation that although the difference in FM rate between the assigned song and personal song did not reach statistical significance, there was a visible increase in rate for the personal song.

FM extent. The FM extent of vibrato has previously been reported in the range of .41 to 1.58 ST (Howes, 2004). In this study, the average extent was about 1.5 ST, with a range from approximately 1.1 ST to 2.0 ST. The patterns for FM extent across the pitch and loudness continua are very similar, allowing the results to be considered together. Figure 2 and Figure 3 show intriguing patterns of change for FM extent. First, there is a modest but steady increase in extent from the low to the high pitch and loudness conditions. For the sustained vowel tasks, the extent increased with mean f0. Second, and perhaps more significantly, there was a greater difference between the isolated vowels and the performance tasks in the extent of vibrato. The personal selection showed almost no difference from the assigned selection, which suggested that the level of emotion may not have had much of an effect on vibrato extent. Instead, the nature of the task had a significant impact on FM extent. It could be speculated, based on this finding, that FM extent is not tied to emotion, but rather increases during performance, in contrast to the sustained, isolated vowel tasks that are not representative of concert performance.

FM rate COV. Vibrato rate steadiness was measured in this study as FM rate COV. This measure was used as the method of examining the consistency of the FM rate. In a previous study, vibrato rate periodicity was described as an important component of vocal beauty (Rothman, 2003). The term periodicity usually includes both rate and extent measures to assess the overall steadiness of a sound in comparison to a sine wave. In this study, however, rate steadiness and extent steadiness have been examined individually in an attempt to more specifically examine the timing and amplitude components of vocal vibrato. In a previous study, a steadier vibrato was favored by expert listeners over a less steady vibrato (Robison et al., 1994). Therefore, the examination of FM rate COV could give insights into the way that emotion affects the overall beauty of vibrato.

In this study, the FM rate COV patterns across the pitch and loudness continua were found to be alike, as seen in Figure 2 and Figure 3. In both graphs, the FM rate COV showed a slight decrease in unsteadiness with an increase in the pitch and loudness for the sustained vowel tasks. This decrease was subtle compared to the substantial decrease in FM rate COV between the sustained vowels and the assigned song. The size of this change suggests that FM rate COV is affected by the performance nature of the task. The FM rate COV for the personal selection was likewise significantly lower than for the sustained vowel tasks. It is important to note, however, that the personal selection was slightly higher in FM rate COV than the assigned song. Although this difference was not statistically significant, there is a visible difference between the songs in Figure 2 and Figure 3. The increase in unsteadiness from the assigned song to the personal selection may permit speculation that the presence of more intense emotion increases FM rate inconsistency. This may be linked to the the previously identified relationship between fear, or anxiety, and a quivering voice (Merritt, Richards, & Davis, 2001).

FM extent COV. FM extent COV is the measure of inconsistency in the width of the vibrato extent during each vowel token. Inferences about this vibrato characteristic mirror those of the FM rate COV. A slight decrease in extent variability was noted between the low pitch and loudness tasks and the high pitch and loudness tasks within the sustained vowels, showing an inverse relationship between pitch/loudness and FM extent COV. The most significant difference was between the isolated vowel tasks and the performance tasks, with FM extent COV decreasing significantly for the performance tasks. These results, when applied to real performance, could suggest that the FM extent is more stable during performance and less stable during vocal tasks that are not part of a singer's concert performance, such as warm-up activities.

With regard to emotion, FM extent COV did not appear to be affected by increased emotion in the way that FM rate COV was affected. There was no noticeable difference between the extent COV for the neutral-emotion assigned song and the high-emotion personal selection.

General Discussion

The purpose of this study was to learn whether the emotion expressed by a singer during performance would influence the acoustic characteristics of their vibrato. The results not only link certain aspects of vibrato to emotion, but also to singing in performance as opposed to the production of isolated vowels. FM rate and FM rate COV appeared to change in connection with emotion, while FM extent, FM rate COV, and FM extent COV appeared to be influenced by the task (performance of a song versus isolated vowel phonation).

The personal song was the only condition in the study under which the singers would be anticipated to perform with intense emotion. However, singing in the recording studio as part of an experiment would only poorly simulate the experience of performing before a large audience. Thus, the personal selection was potentially more representative of a performance practice session. Furthermore, when singing even an emotional song, the singers may not necessarily have been experiencing a powerful emotion. Professional singers may simply be skilled in the technique of portraying an emotion during performance without actually feeling it personally.

One way to understand this phenomenon more fully would be through an examination of the physiological changes in the singer while performing with emotion during a live stage event. Relevant measures could include cardiac, electrodermal or vascular measures such as cardiac interbeat intervals, skin conductance level, diastolic blood pressure and mean arterial pressure. These measures have been used in previous studies to assess physiological changes in individuals while they listen to emotional operatic music (Baltes et al., 2011, Krumhansl, 1997), and could potentially be adapted to assess the emotional arousal of the singer during performance. This type of study could give a clearer understanding of whether singers genuinely experience emotions during a performance, or whether they are instead highly skilled at simulation, having practiced the emotional song so many times that they need not experience the actual emotion during performance in order to convincingly evoke it in the audience.

Limitations and Directions for Future Research

The degree to which we can generalize from the current study was limited because there were only ten participants – eight females and two males. In the future, a larger number of participants with approximately equal representation of men and women might yield results that are easier to interpret, particularly with regard to any differences between males and females in the influence of emotion on vibrato. In the present study it was difficult to directly compare the personal selections with other tasks because the personal selection was different for each participant, while all other tasks were completed in the same way for each singer. A possible solution in future research would be to have all participants sing the same high-emotion song. This may still present problems if the high-emotion selection is unfamiliar to some participants.

In this study, high-emotion and neutral-emotion were the only two categories used to describe the emotion in the singing tasks. In future studies, the type of emotion could be further examined in several ways, including comparisons of positive and negative emotions, or specific emotions such as anger, fear, pride, sadness, and so on. A more specific method of classifying emotion may lead to a clearer understanding of how emotions influence the singing voice.

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Ferrante, I. (2011). Vibrato rate and extent in soprano voice: A survey on one century of singing. *The Journal of the Acoustical Society of America, 130*(3), 1683-1688. doi: 10.1121/1.3621017

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Horii, Y. (1989). Acoustic analysis of vocal vibrato: A theoretical interpretation of data. *Journal of Voice, 3*(1), 36-43.

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Appendix A

Annotated Bibliography

Baltes, F. R., Avram, J., Miclea, M., & Miu, A. C. (2011). Emotions induced by operatic music: Psychophysiological effects of music, plot, and acting: A scientist's tribute to Maria Callas. *Brain and Cognition, 76*(1), 146-157. doi: 10.1016/j.bandc.2011.01.012

Objective: The goal of this study was to examine the influence of music, plot, and acting on emotional responses. Subjective and physiological responses to operatic music were investigated. *Methods:* Volunteers included 37 Romanians with good health and little familiarity with the selected musical piece. Two excerpts of an opera were played for each participant, once with listening only, once listening after knowing the plot, and once while watching video of the scene and listening. Participants were monitored with an ECG, physiological electrodes, blood pressure monitor, and a respiration transducer. Self-report measures and physiological measures such as respiration, blood pressure, and skin conductance were evaluated. *Results:* Musical experience had a significant main effect on self-reported emotional arousal and physiological responses. Watching the acting performance significantly increased emotional arousal in comparison to learning the plot or only listening to the music. *Conclusions:* Listening to the music, learning the plot, and watching the acting of an opera all have an effect on music-induced emotions. Watching the acting while listening to the music brings the most physiologic change. *Relevance to the current work:* This work shows that experiencing music influences the emotions of the listener. It could likewise be hypothesized that emotions influence the performance of music.

Brown Jr, W. S., Rothman, H. B., & Sapienza, C. M. (2000). Perceptual and acoustic study of professionally trained versus untrained voices. *Journal of Voice, 14*(3), 301-309.

Objective: This experiment was designed to investigate the effects of vocal training on an individual's everyday speaking voice, using acoustic and perceptual measures. *Methods:* Participants for this study included 20 professionally trained singers and 20 age-matched non-singers. Each participant performed three tasks, including both speaking and singing voice. Stimulus tapes were played for listeners, and listeners judged each recorded phrase (N=80), identifying the professional singers and nonsingers from their utterances. Several frequency and timing measures were taken from isolated /i/ vowel production and the Rainbow Passage. These measurements were analyzed for acoustic differences between professional singers and nonsingers using the *Multidimensional Voice Program* software. Presence or absence of vibrato was also determined using each singing phrase through Fast Fourier Transform power spectra and auditory perception. A nonparametric *t* test was performed on the data with a 0.05 confidence level for significance. *Results:* Identification of professional singers from nonsingers during singing tasks was 87% accurate. Listeners only achieved 57% correct identification during speaking tasks. Acoustic analysis showed slight differences between speaking and singing voice, but no consistent or reliable differences were found. Most obvious differences were found in the presence/absence of vibrato in comparing the groups. *Conclusions:* While there were apparent differences between trained and untrained singing voices, there were no significant differences in the speaking voice of professional singers and nonsingers. *Relevance to the current work:* While professional training may not have an effect on speaking voice, it does change the perceptual and acoustic features of the singing voice, most prominently the presence of vibrato.

Corso, J. F., & Lewis, D. (1950). Preferred rate and extent of the frequency vibrato. *Journal of Applied Psychology, 34*(3), 206-212.

Objective: This study was designed to examine trained and untrained listener preferences for vocal vibrato, specifically the preferred combination of rate and extent. *Methods:* Multivibrators were used to create five tones, each an octave apart, that were harmonically rich. A frequency vibrato control unit managed change in vibrato rate and extent. Rates of oscillation were 5.5, 6.0, 6.5, and 7.0 pulses per second, and extent of modulation included 0, 0.10, 0.25, and 0.40 of a musical step. 385 participants were divided into two groups: 1) individuals with little to no musical training, and 2) individuals with sufficient musical training to be part of the University of Iowa symphony orchestra or chorus. Each group of subjects was exposed to various pitch, rate, and extent variations. Untrained groups were also given the Seashore timbre test battery. *Results:* Comparisons led to a rank order scale of vibrato preference. For trained singers, the most preferred vibrato tone had an extent of 0.10 and a rate of 6.5 pulsations per second. Extent had a greater effect on vibrato preference than rate. For untrained subjects, the most preferred vibrato tone had a vibrato rate of 6.0 and extent of 0.25. A Chi Square test determined that differences between trained and untrained subjects was significant. *Conclusions:* Rates of 6.0, 6.5, and 7.0 were about equally preferred, and an extent of 0.25 was preferred. Native auditory ability had little effect on vibrato preference, and trained and untrained individuals all tended to prefer the same rates, but trained individuals prefered a narrower extent. *Relevance to current work:* Preferred vibrato rates include 6.0, 6.5, and 7.0 pulsations per second, and preferred vibrato extent is 0.10 to 0.25 of a musical step. Musical training has an effect on vibrato preferences.

Dromey, C., Carter, N., & Hopkin, A. (2003). Vibrato rate adjustment. *Journal of Voice, 17*(2), 168-178.

Objective: The goal of this study was to conduct a detailed acoustic analysis of volitional vibrato adjustments, specifically examining changes in vibrato rate, extent, and steadiness. *Method:* There were two phases of this study. The first involved 12 singers, who recorded sustained vowel productions in various pitches and vocal registers without instruction regarding vibrato rate. The second phase involved 8 singers, who were asked first to produce a target vowel in their normal manner, and then to attempt to match the pitch and vibrato rate of a stimulus given through headphones, which were samples from the initial phase of the study. The Motor Speech Profile module of CSL was used for preliminary analysis of each singer's vibrato, and further analysis was conducted using Matlab. *Results:* Individuals varied in their ability to match the vibrato rates of prerecorded stimuli in each register. For chest register, there was a significant correlation between singers' natural FM rate and their rates for slow and fast matching. For head register, there was significant correlation between natural and slow conditions. For chest register there was also a positive correlation between FM rate and FM extent across natural and matching conditions. Slower FM rates were generally less steady in rate and extent. *Conclusions:* Vibrato rate can be adjusted, but the exact mechanism of vibrato rate adjustment cannot be inferred from the current data. *Relevance to current work:* Vocal vibrato can be adjusted volitionally, although the exact origin of those changes is unknown. Slower vibrato rate is associated with a less steady rate and extent.

Dromey, C., Reese, L., & Hopkin, J. A. (2009). Laryngeal-level amplitude modulation in vibrato. *Journal of Voice, 23*(2), 156-163. doi:S0892-1997(07)00068-9 [pii] 10.1016/j.jvoice.2007.05.002

Objective: This study was designed to examine in detail whether AM arises at the laryngeal level in trained singers, or whether it arises solely as a result of the resonance-harmonics interaction (RHI). *Methods:* Participants included 17 female trained singers, who each produced 27 recorded samples, including three pitches and three levels of loudness. Each singer was equipped with a head-mounted microphone to record phonation, as well as an EGG to measure vocal fold contact during phonation. Various signals were analyzed, including the fundamental frequency from the mic, fundamental frequency from the EGG, and amplitude modulation from the mic. The EGG speed quotient was calculated, and SPL changes were also examined. *Results:* EGG AM extent showed significant change as a function of loudness in pitch-collapsed data. EGG AM extent was not significantly influenced by pitch, and it varied substantially between individuals singers and among each singer's 27 samples. *Conclusions:* Modulations detected by the EGG speed quotient were considered evidence of laryngeal level AM. RHI is still considered the main source of AM in vibrato, and AM is still added to the output from RHI even when laryngeal AM is present. Findings are consistent with the idea of motor equivalence. *Relevance to current study:* AM output is a result of both RHI and a laryngeal component. Levels of AM from the larynx and the RHI vary among individuals, suggesting that not everyone achieves pleasing vibrato with the same exact motor patterns. Laryngeal contribution to AM can be measured from the EGG signal.

Ekholm, E., Papagiannis, G. C., & Chagnon, F. O. P. (1998). Relating objective measurements to expert evaluation of voice quality in western classical singing: Critical perceptual parameters. *Journal of Voice, 12*(2), 182-196.

Objective: The goal of this pilot study was to identify critical spectral characteristics associated with four criteria of *good* vocal production, and their effects on the perception of vocal quality in Western classical singing. The four criteria were *resonance/ring*, *clarity/focus*, *color/warmth*, and *appropriate vibrato*. *Method:* Sixteen male singers were asked to sing an excerpt from Mozart's aria "Ch'io mi scordi di te." Three vowels were extracted for spectral analysis, for which a frequency range, mean frequency, mean spectral amplitude, and spectral area were calculated. The vibrato rate, vibrato extent, and time delay of onset of vibrato were also calculated. Expert voice teachers judged each performance and each vowel segment, rating each of the perceptual criteria from 1 to 7. *Results:* Expert ratings of the complete excerpt correlated most with the expert ratings of the /a/ vowel segment and least with /i/ segments. Expert ratings were also compared with acoustic variables. Of the three vibrato measures, only time delay until onset had a notable correlation with appropriate vibrato rating. *Color/warmth* related strongly with *appropriate vibrato*. *Conclusions:* High standards of voice quality in male professional singers include expectations of accurate intonation, sustained vibrato with well-balanced rate and extent, and presence of a singer's formant in the critical bandwidth of hearing. *Relevance to the current work:* Time delay of onset and absence of vibrato have a negative effect on vocal quality ratings. Percentage of amplitude modulation also affected overall ratings, in that high amplitude modulation results in lower ratings. Having a balance in vibrato rate and extent is important for professional singers, such that a combination of lower rate and larger extent leads to lower expert listener ratings.

Ferrante, I. (2011). Vibrato rate and extent in soprano voice: A survey on one century of singing. *The Journal of the Acoustical Society of America, 130*(3), 1683-1688. doi:10.1121/1.3621017

Objective: This study examined a single tone from over 100 performances over the past century in order to observe differences in vibrato characteristics over the course of the 20th century. *Method:* The tone used in this study was the B-flat on the word "*Signor!*" in the aria "*Vissi d'arte*" by Giacomo Puccini. This study included 105 tones, at least five recordings per decade between 1900 and 2010, collected from all possible sources and sung by 75 different singers. Fundamental frequency was calculated, and spectral analysis was conducted to examine each sample. Vibrato rate and amplitude were calculated and correlated, and mean intonation (MF0) was also measured. *Results:* Mean vibrato rate was 6.22 Hz, and mean extent was 68 cents. There was a clear positive correlation between time and intonation, and a negative correlation between rate and extent. Vibrato rate increased during the last 10 cycles. *Conclusions:* Over the course of the past century, preferred vibrato rate had decreased by 1.8 Hz/century and extent has increased by 56 cents/century. *Relevance to the current work:* Preferred vibrato rate and extent have changed over time. Average vibrato rate of professional singers can change based on popular trend, but this pattern of decreasing rate also follows the changes in vibrato rate with age.

Harrop, J. (1992). Acting. *Chapter 1: Acting and the phenomenological problem*, *Chapter 5: The psychology in acting*. Routledge: Florence, KY. Pgs. 4-9, 32-43.

Chapter 1: Unlike artists, musicians, dancers and other performers, actors must be both themselves and another person at the same time. They are not the subject of their performance, but instead they exist as someone who is not actually present—their character. The duality of the actor on stage is an essential element of theater, as is the duality of emotion and technique in their performance. The task of an actor is to make what is artificial seem genuine. *Chapter 5*: Actors have the task of combining passion and gestures in the most effcient manner to impose emotion upon the audience. It requires both good judgment and good taste as bases of an actor's technique. Mastery of technique relies upon the ability to express feelings that are not experienced. The free expression of an individual's desires and and feelings is an essential dynamic of human action, which principle shows the importance of emotion and feelings in theater. Also, the evolution of American theater had much to do with individuality, honesty, and realism becoming important aspects of the acting world. 'Emotion memory' taught actors to simulate emotion in the present by recreating in their imagination the circumstances of a certain past event that brought about the same emotions or feelings. *Relevance to the current work*: In theater, the goal is to portray what seems to be genuine emotion and feeling. The technique of emotion memory helps actors create real emotion from what is otherwise an invented feeling. Actors must combine passion and gesture to persuade the audience of a particular feeling or idea. Actors must be themselves and another at the same time, forcing them to sort through personal and character emotions, and show the audience only what is of the character. This is relevant to opera performance as well. Proper display of emotion and feeling are essential to the success of a persuasive performance.

Horii, Y. (1989). Acoustic analysis of vocal vibrato: A theoretical interpretation of data. *Journal of Voice, 3*(1), 36-43.

Objective: This study provided a theoretical analysis of acoustic data regarding amplitude modulation, as well as phase relationships between amplitude modulation and frequency modulation within vocal vibrato. *Summary*: Recorded samples of vocal vibrato were analyzed through a spectrogram. Evidence of AM in-phase with FM, AM out-of-phase with FM, and nondefinitive AM were all noted. Previous data and review of literature suggest the hypothesis that most amplitude modulations are the result of RHI rather than active amplitude fluctuation. Frequency modulation (F_0) and intensity modulation (I_0) relate in that if intensity function has a negative slope, F_0 and I_0 will be out-of-phase, and if intensity function had a positive slope, F_0 and I_0 will be in-phase. Phase relationships may drift in and out of phase within one phonation at one pitch level, therefore resonances can change while one sings with vibrato. Amplitude modulation can be double-peaked when harmonics are close to the intensity function maxima or minima. There are certain limitations to the RHI hypothesis, including the lack of explanation of how FM is produced. *Relevance to the current work*: The resonance-harmonics interaction hypothesis accounts for most of amplitude modulation. The singer actively produces some AM. The phase relationship between frequency modulation and intensity modulation was explained.

Horii, Y., & Hata, K. (1988). A note on phase relationships between frequency and amplitude modulations in vocal vibrato. *Folia Phoniatrica et Logopaedica, 40*(6), 303-311.

Objective: This study proposed a resonance-harmonics interaction to explain the primary source of amplitude modulation. Phase relationships between frequency modulation (FM) and amplitude modulation (AM) were also discussed. *Summary*: FM is the main component of vibrato. AM and its phase relationship to FM arise as a result of the resonance-harmonics interaction. Resonance-harmonics interaction (RHI): For a given spectral envelope, as F_0 changes, harmonic frequencies and their intensities are adjusted by the resonant properties of the vocal tract. This results in a change of overall intensity. The alignment of harmonics with peaks in resonance changes with the increase or decrease of F_0, thus modifying the intensity of various harmonics with F_0 change. The overall intensity is calculated by the sum of the square height of all harmonics; therefore overall intensity changes based on harmonic-resonance alignment. There should be an in-phase relationship or out-of-phase relationship between F_0 and intensity modulation (I_0) based upon the specific region/range of F_0 modulation. F_0 modulations in a frequency region where intensity function has positive slopes will create in-phase I_0 and F_0 modulation. F_0 modulations in regions where intensity function has negative slopes will create out-of-phase modulations of I_0 and F_0. The accepted average I_0 modulation for vocal vibrato is 2-3 dB. Limitations of the RHI hypothesis: Spectral envelopes could be altered during vocal vibrato due to elevation of larynx or movement of soft palate and jaw. Sung vowels may have greater amplitudes of higher harmonics than in normal speech. The RHI effect may has less significance during extreme performance such as very soft or very loud performance, or very high/low pitch performance. *Relevance to the current work*: Vocal vibrato mainly consists of FM. AM arises mostly from the resonance-harmonics interaction. The RHI explains the relationship between harmonics and resonance patterns, which contribute to overall intensity. The phase relationship between F_0 and I_0 depends on F_0 region and range. There are some limitations to the RHI hypothesis.

Howes, P. (2004). The relationship between measured vibrato characteristics and perception in Western operatic singing. *Journal of Voice, 18*(2), 216-230. doi: http://dx.doi.org/10.1016/j.jvoice.2003.09.003

Objective: This article included three related studies that examined the acoustic features of vibrato in vocal performance, compared the perceived attributes with acoustic measurements, explored the possible relationship between vibrato and listeners' preferences for singers, and considered whether vibrato might influence listeners' perceptions of the emotion communicated in the performance. *Method*: An aria was chosen for each study. In Study 2 and Study 3, an aria with strong emotions was chosen. Each selection was analyzed for vibrato rate and extent. Study 1 used the perceptual results from the Siegwart and Scherer study, and Studies 2 and 3 included their own perceptual experiments. Study 2 included professional singing teachers, and Study 3 included self-selected opera lovers. Participants in both studies were aked to judge music excerpts based on their personal preference. *Results*: Study 1—Average vibrato rates varied from 7.14 to 6.28 Hz. Vibrato extent was the widest at 1.22 semitones. The most preferred singer had an average vibrato rate. Study 2 and Study 3—Vibrato extent varied widely, between 0.41 and 1.58 ST. Music excerpts that were most commonly considered best were the ones with a rate that was not too fast or too slow, and an extent that was not too large or too small. *Conclusions*: Perceptions of vibrato features did not generally display a clear relationship to the actual acoustic measurements of vibrato. As Seashore concluded, this study also concluded that unless vibrato was innapropriate or obtrusive, the listnener did not make fine distinctions about it. The least preferred singers had the widest extent overall, and the most preferred singers had a narrow overall extent. Vibrato onset and extent appeared to be closely related to preference. Judges in Study 3 were able to successfully identify the singer's emotion, which shows that the singer's successfully conveyed the target emotion. Tempo could have had an effect on emotion judgements in this study. *Relevance to the current work*: Vibrato onset and extent are related to preference. Perceptual judgements of vibrato are not finely tuned even in professional music teachers.

Ilie, G., & Thompson, W. F. (2006). A comparison of acoustic cues in music and speech for three dimensions of affect. *Music Perception, 23*(4), 319-329. doi: 10.1037/0022-3514.70.3.614

Objective: This study examined the effects of manipulating intensity, rate, and pitch height in music and speech using a three-dimensional model of affect. *Method:* Participants included 27 undergraduate psychology students with an average of 3.4 years of formal music training. Stimuli included 8 excerpts of speech and 8 excerpts of music, manipulated into 2 different pitches, 2 tempi or speaking rates, and 2 intensities each, with a total of 64 music stimuli and 64 speech stimuli. Ratings for each sample were obtained from the participants for each of the three dimensions of affect: valence, energy arousal, and tension arousal. *Results:* There was a main effect of domain for energy arousal and for valence associated with music. There were significant valence interactions between domain and pitch height, domain and rate. For energy arousal ratings, there were significant interactions between intensity and domain, and rate and domain. For tension arousal there were significant interactions between intensity and domain, and rate and domain as well. *Conclusions*: Manipulations of pitch height, rate, and intensity had affective consequences in both speech and music. These conclusions suggest that pitch height, intensity and rate provide listeners with valuable perceptual information to decode emotion in both music and speech. *Relevance to the current work:* Rate, pitch height, and intensity are all features of speech and music that help a listener decipher emotion.

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology, 51*(4), 336-353. doi: 10.1037/1196-1961.51.4.336

Objective: This study was designed to examine whether music elicits emotional responses in listeners, or simply expresses emotions that listeners recognize in the music. This was determined through several psychophysiological measures. *Method:* Thirty-eight university students who had each received at least seven years of instruction with a musical instrument or voice participated in the study, which involved listening to music that either portrayed sadness, happiness, fear, or tension. Participants listened to six excerpts, each approximately three minutes in duration, while several psychophysiological measures were calculated. These included cardiac interbeat interval, pulse transmission time to finger, finger pulse amplitude, pulse transmission time to the ear, respiration intercycle interval, repiration depth, repiration-sinus asynchrony, systolic blood pressure, diastolic blood pressure, mean arterial pressure, skin conductance, and temperature on the finger. Averages of the physiological measures pre-music were subtracted from the average measures during the listening task in order to account for individual differences in pre-listening physiology. *Results:* Compared with the pre-music baseline levels, music had a significant effect on all 12 physiological measures. Conclusions: The changes in physiological measures while listening to music suggests that musical emotions are reflected in psychophysiological measures. These psychophysical changes are behavioral indicators that listeners experience emotions, rather than just recognizing them, while listening to music. *Relevance to the current work:* Individuals experience emotion while listening to music. The presence of emotions during listening can be measured physiologically.

Mendes, A. P., Rothman, H. B., Sapienza, C., & Brown Jr, W. S. (2003). Effects of vocal training on the acoustic parameters of the singing voice. *Journal of Voice, 17*(4), 529-543.

Objective: This study examined the acoustic effects of four semesters of vocal training on maximum phonation frequency range (MPFR), vibrato, and singers' formants produced by voice majors. *Method:* 12 females and 2 males each produced their MPFR and sang an excerpt of "America the Beautiful" with sustained vowels. Spectral measurements and formant trajectory were calculated, and an acoustic analysis was performed to find F0 range and SPL. Vibrato rate and amplitude variation were measured and an FFT was used to find the presence or absence of the singers' formant. *Results:* Two mesures of MPFR, $F_0$90 and $F_0$90-10, increased as voice training progressed. SPL90 and SPL90-10 both increased with more voice training as well. Singers' formant had inconsistent changes with voice training and classification. *Conclusions:* Voice training had a significant effect on the MPFR fundamental frequency and vocal intensity, but not on vibrato or singers' formant. *Relevance to the current work:* Even though voice majors already have some natural vibrato ability, four semesters of vocal traning may not be enough to change or stabilize vibrato production. It may take several years to learn to produce a stable vocal vibrato.

Merritt, L., Richards, A., & Davis, P. (2001). Performance anxiety: Loss of the spoken edge. Journal of Voice, 15(2), 257-269. doi: http://dx.doi.org/10.1016/S0892-1997(01)00026-1

Objective: This study was designed to assess whether a specific vocal and physical training program could reduce perceived performance anxiety. *Method:* Eighteen performing arts undergraduate students participanted in this study. Two groups of equal numbers were created; one group experienced 10 two-hour sessions in a specified vocal or athletic training program. The other group received the same number of lessons in text analysis. Two weeks after the programs were completed, both groups gave a short speech of general interest while being videotaped. Vocal and physical features were analysed including physical ease, physical presence, effective gesture use, effective eye contact, correct breath use, suitable pace, vocal variety, speech clarity, and perceived performance anxiety. *Results:* The group who received vocal and physical training scored significantly higher on each of the eight measures, which indicated positive results in reducing the level of perceived performance anxiety. *Conclusions:* Individuals who are involved in vocal or physical performance on a regular basis could benefit from a communication skills training program. Those affected by performance anxiety could benefit from explicit discussion of the basic skills of vocal delivery. *Relevance to the current work:* Anxiety can be detected through changes in the voice, as well as overall appearance and behavior. A relationship exists between vocal clarity and performance anxiety.

Mitchell, H. F., & Kenny, D. T. (2010). Change in vibrato rate and extent during tertiary training in classical singing students. *Journal of Voice, 24*(4), 427-434.

Objective: This study examined changes in vibrato rate and extent over the course of 2 years of tertiary vocal training for university voice majors and minors, identifying any systematic changes that occurred during this training. *Method:* Twenty-eight voice majors, minors, and Diploma of Opera students were asked to perform four *messe di voce* (MDV) exercises at various pitches. Each singer sang on one occasion per semester for 2 years, for a total of 4 times. An acoustic analysis was performed on each recording in 100-ms intervals to calculate vibrato rate and extent. The effect of dynamic range on vibrato rate and extent were also examined. One overall number for rate and extent was calculated for each student per semester in order to show change over time. *Results:* The average rate decreased and extent increased over the 4 semesters. Only vibrato extent showed statistically significant differences between semesters. The vibrato rate SD had significantly decreased between semester 1 and 3-4. Vibrato rate periodicity improved significantly as well. *Conclusions:* Systematic longitudinal differences in vibrato characteristics during tertiary training were found in this study. Vibrato rate slightly decreased and extent significantly increased over time. Consistency of rate improved, while consistency of extent stayed the same. *Relevance to the current work:* Tertiary vocal training can change vibrato parameters. This shows that training does have an effect on vibrato characteristics and consistency.

Murbe, D., Zahnert, T., Kuhlisch, E., & Sundberg, J. (2007). Effects of professional singing education on vocal vibrato—A longitudinal study. *Journal of Voice, 21*(6), 683-688.

Objective: This study was designed to document the effects of professional singing education on vibrato characteristics such as vibrato rate and standard deviation (SD), as well as the influence of vocal loudness on these characteristics. *Method:* Twenty-two singing students were examined at the beginning and end of 3 years of professional soloist education. Each participant was asked to sing an ascending-descending three-tone triad pattern on a vowel at a comfortable pitch. Two loudness levels (medium and soft) were used. Mean vibrato rate and SD of rate were measured. F0 and periodicity properties were also observed. *Results:* A high reproduceability was found for mean vibrato rates. The SD of vibrato rate was significantly higher for the piano (soft) condition than the mezzoforte (medium) condition. Loudness level failed to affect the average vibrato rate. Singers with the fastest and slowest vibrato rates before training had reached more normal vibrato rates after training. *Conclusions:* After 3 years of professional voice training, voices with fast vibrato had slowed down, voices with a slow vibrato had sped up, and voices with an irregular vibrato showed a more regular vibrato after training. *Relevance to the current work:* An idividual's vibrato characteristics can change due to professional singing education and training.

Patel, S., Scherer, K. R., Bjorkner, E., & Sundberg, J. (2011). Mapping emotions into acoustic space: The role of voice production. *Biological Psychology, 87*(1), 93-98. doi: 10.1016/j.biopsycho.2011.02.010

Objective: This study examined the degree to which the expression of emotion in speech is recognized by vocal quality. *Method*: Speech samples were taken from ten professional French-speaking actors who portrayed a variety of emotions. They each expressed an affect burst, or a sustained /a/ vowel, in 12 different emotional contexts. Emotions included relief, sadness, joy, panic fear, and hot anger. Differences in affect dimensions of arousal, valence, and power/potency were all represented including alert/excited to relaxed/calm, positive valence to negative valence, and high control to no control. Twelve acoustic parameters were extracted from speech samples including jitter, shimmer, mean F_0, equivalent sound level, and harmonic-to-noise ratio. Extraction from inverse filtering allowed analyses of pulse amplitude, maximum flow declination rate, normalized amplitude quotient, closed quotient, and level difference between first and second harmonics. Separate repeated measures analyses of variance were performed for each acoustic parameter with emotion as the within subjects factor. *Results*: This analysis proved that the acoustic parameters were useful in discriminating between at least two emotions. There was a significant main effect of emotion on 11 of the 12 parameters. The results suggest that emotions can be expressed in three underlying components: phonatory effort (subglottic pressure and vocal fold adduction), phonation perturbation (hyper- and hypotension of vocal fold adduction), and phonation frequency (vocal folds vibration rate). *Conclusions*: Voice quality is a central aspect of emotional speech. Phonatory effort/tension, frequency, and perturbation are all necessary in order to differentiate emotions. *Relevance to the current work*: One important aspect of emotional speech is voice quality, which includes the perturbation, frequency and effort of phonation.

Prame, E. (1994). Measurements of the vibrato rate of ten singers. *The Journal of the Acoustical Society of America, 96*(4), 1979-1984.

Objective: This study focused on the frequency modulation aspect of vibrato, investigating three aspects of vibrato rate: the intra-tone aspect, inter-tone aspect, and inter-artist aspect. *Method:* Musical performances of *Ave Maria*, by Franz Schubert, were selected from CD recordings of 10 prominent contemporary artists of the Western classical music tradition. A spectral analysis was conducted on the same 25 tones from each performance, and vibrato cyces were measured. *Results:* The average rate between all 10 singers was 6.0 Hz . Vibrato rate increased toward the end of each tone for all singers, as well as other musical instruments that were examined. This pattern may have an effect on average vibrato rate of tones based on their duration. *Conclusions:* Excluding the last 2-5 cycles of each tone, the average rate was 6.0 Hz. This study concluded that previous calculations of vibrato rate may be unreliable because no typical vibrato pattern could be measured in the beginning of the tones, and an increase in rate was shown at the end of tones. *Relevance to the current work:* Average vibrato rate was 6.0 Hz. Findings show that rate may not be consistent through a single tone.

Robison, C. W., Bounous, B. U., & Bailey, R. (1994). Vocal beauty: A study proposing its acoustical definition and relevant causes in classical baritones and female belt singers. *NATS Journal, 51*(1), 19-30.

Objective: This study examined the acoustic and postural characteristics that contribute to vocal beauty. *Method*: Two groups of samples were used. The first sample contained recordings from 19 baritones including 13 undergraduate voice majors and six master's degree professional opera singers. The second sample contained recordings from eight trained female belt singers who were music dance theater majors. DAT recordings received a *beauty* ranking from 13 expert judges on three panels: voice teachers, voice scientists, and voice connoisseurs. Judges rated singing samples on a scale of 0-10, 0= rudimentary, 10= flawlessly beautiful. For baritone samples, judges were also asked to check boxes labeled *overbright*, *nasal*, *dull*, or *balanced* as appropriate. *Results*: Judges were in considerable agreement on beauty rankings of the 19 baritones and the eight belt singers. The average score for belt singers was significantly lower than for baritones. The highest ranking singers, or most beautiful singers, displayed *legato,* or vibrato presence and evenness throughout the sung phrase. Beautiful singers used more even vibrato. Vibrato was present in most the beautiful singing baritones in over 80% of total singing time. The top belt singer used vibrato in over 50% of her singing time. The beautiful voices showed moderate vibrancy of vibrato rate and extent. In belt singers, a moderately faster and narrower vibrato is preferred than in baritones. In baritones, a brighter-toned voice is preferred, and in belt singers, the darker-toned voice is preferred. Beauty ranking is highly correlated with relative cleanness of the voice. Nasality and posture are poor predictors of vocal beauty. Good breath management is a good predictor of vocal beauty. *Conclusions*: 1. A group of listeners who are knowledgeable on the cultural preferences of voice will agree with statistical reliability on the relative beauty of singing samples. 2. All acoustic measurements that show statistically significant and consistent correlations with vocal beauty rankings of informed judges imply a reliable definition of beautiful singing within that culture. 3. All aerodynamic and postural measurements that show significant and consistent correltions with vocal beauty rankings can be assumed to be relevant causes to the 'beautiful' acoustical patterns they present. *Relevance to the* *current work*: Moderate vibrato rate and extent are preferred in a 'beautiful' voice. Presence of vibrato in a high percentage of total singing time is preferred. Cleanness of voice and breath management are good predictors of vocal beauty.

Rothman, H. B. (2003). Acoustical comparison between samples of good and poor vibrato in singers. *Journal of Voice, 17*(2), 179-184.

Objective: This study investigated the relationship between professional vibrato rating and periodicity of vibrato in order to confirm or reject the hypothesis that the best vibrato samples are the most periodic samples. *Method*: Eight professional singers were chosen as participants. Four other individuals with singing experience and knowledge of the singing voice were used as judges. The judges classified singing samples as good or poor, good meaning pleasing to the ear and poor meaning disagreeable to the ear. Five samples of unanimously determined good vibrato and five samples of poor vibrato from each singer were chosen for analysis. Vibrato frequency was determined by the sixth harmonic in example spectrograms of each vibrato sample. The LPC method was used to create time-varying extent and rate of the vibrato wave. Periodicity was measured through four parameters: total time varying rate deviation, variability of the time varying rate, total time varying extent deviation, and variability of the time varying extent. *Results*: The mean values of the variables were higher for four out of eight singers' poor samples. Variability in rate was higher for the poor samples than the good samples. Variability in extent was also higher for poor samples than good samples. Mean values for all four parameters of periodicity were always smaller for good samples. *Conclusions*: The original hypothesis was supported by the results that the most symmetrical and periodic samples were judged as the best samples. Time varying extent was the most meaningful measure to predict rating. Also, oscillations in the rate and extent were seen mostly in extent, which shows that vibrato extent was more difficult for singers to control than rate. *Relevance to the current work*: There is direct relationship between the perceived quality of a vibrato sample and its periodicity. Vibrato extent is more difficult to control than vibrato rate. Vibrato extent consistency is more indicative of perceived quality than rate consistency.

Ruiz, M. D. (2008). Effects of positive and negative emotion elicitation on physical activity performances (Unpublished doctoral dissertation). University of Minnesota, Minnesota.

Objective: This study was designed to examine how the elicitation of a positive, negative, or neutral emotion affected the performance of physical activity and sport. *Method:* Participants completed one of three activities: cup stacking, vertical jumping, or basketball free throw shooting. Each participant participated in three different conditions: post-positive film viewing, post-negative film viewing, and post-neutral film viewing. Qualitative data were collected through questionnaires and interviews, while quantitative measurements of time, meters jumped, and points earned for each skill were calculated. *Results:* There was a significant difference between positive, negative, and neutral emotion on cup stacking performance speed. Positive or negative emotion versus neutral emotion led to significant differences in vertical jump height. Positive, negative, and neutral emotion conditions had no significant effect on free throw performance. *Conclusions:* Positive emotion and negative emotion are beneficial for gross motor skills over neutral emotion. *Relevance to the current work*: Positive and negative emotion have an effect on physical performance. The type and intensity of emotion may change the effect on performance, whether it helps or hinders performance.

Seashore, C. E. (1931). The natural history of the vibrato. *Proceedings of the National Academy of Sciences, 17*(12), 623-626.

Summary: The definition of an artistic vibrato is a periodic oscillation in pitch in which the extent of oscillation for the best singers averages approximately a half-tone, at an average rate of approximately 6 or 7 cycles per second, and is usually accompanied by synchronous timbre and intensity oscillations which play a secondary role. A good vibrato is a periodic pulsation involving pitch, intensity, and timbre. A good vibrato also adds richness to the voice. Vibrato is found in singing and emotional or dramatic speech, and it has been noticed in more primitive peoples as well as people in Seashore's time. Vibrato is also used by experienced string and wind instrument players. Pitch, intensity, and timbre each vary in extent, rate, and form. Extent is the distance between the top and bottom of the crest, and is measured in semitones or fractions of a tone. The average extent is six-tenths of a tone, or roughly one semi-tone. The rate of vibrato is the number of pulsations per second. The current average rate is between six and seven cycles. The average extent of intensity is 2.4 decibels. This investigation also found that vocal vibrato does not significantly change between musical modes, types of emotion or extreme calmness and excitement. This was an unexpected finding because of the assumption that vibrato is a medium for differential expression of emotion. There are four *illusions of vibrato*, which are explained in the article. *Relevance to the current work:* Seashore provided a basic definition of vibrato. Vibrato involves oscillations in pitch, intensity and timbre, each of which has a specific rate, extent, and form. Vibrato rate and extent were defined and explained. Seashore's investigation concluded that there were no significant differences in vibrato characteristics due to presence of level of, or type of emotion.

Solomon, N.P., Ramanathan, P., & Makashay, M.J. (2007). Phonation threshold pressure across the pitch range: Preliminary test of a model. *Journal of Voice, 21*(5), 541-550. doi: http://dx.doi.org/10.1016/j.voice.2006.04.002

Objective: The study examined the relationship between phonation threshold pressure (PTP) and voice fundamental frequency (f0) across the pitch range. The cross-sectional thickness of the vocal folds decreases and mucosal wave velocity increases with an increase in pitch, which is the basis for the hypothesis that PTP would increase with pitch. *Method:* Eight adults with untrained voices participated in two sessions each. Pitch range was determined for each, and 10 target pitches were set in ~10% increments of the individual's range. During the second session, participants produced the 10 target pitches in random order with syllable /pi/ at a consistent rate. Participants produced each pitch at a level louder than threshold, then a whisper, then barely above a whisper (at threshohld). PTP was caluclated from the pressure peaks of /p/ produced without airflow. *Results:* Mean PTP generally increased as pitch increased above a minimum value for most speakers. Four subjects' data were best fit by a quadratic coefficient, two by quadratic functions, and one by linear function. *Conclusions:* PTP might actually be lowest at a comfortable pitch rather than the lowest pitch tested. The established PTP-f0 relationship was generally supported through these findings. *Relevance to the current work:* Phonation threshold pressure increases as pitch increases due to the changes in the mucosal wave velocity and thickness of the vocal folds. This also relates to the required vocal intensity, which increases with an increase in pitch.

Appendix B

Informed Consent

Consent to be a Research Subject

Introduction
You have been invited to participate in a research study about the effects of emotion on the singing voice. This study is being conducted by Sharee Holmes, a graduate student at Brigham Young University, under the direction of Christopher Dromey, PhD, who is a member of the faculty in the Communication Disorders Department. You have been invited to participate because you have vocal competency ratings at or above 3.0, and have no history of hearing or voice disorders.

Procedures

- You will be asked to attend one recording session lasting approximately 30 minutes. This will be your total time commitment beyond your warm-up exercises. The recording session will be held in Studio Y (E-366 HFAC), and sessions will be scheduled during the week of January 21-26, 2013.
- You are expected to arrive at recording sessions having completed individually chosen warm-up exercises on your own in preparation for the 30-minute vocal session.
- You are asked to provide your own accompanist for both sessions.
- You will bring a copy of your personal selection with annotations of emotional rating. You will rate sections of your piece on a scale of 1 to 5, 1 being a section of relatively neutral or low emotion, and 5 being a section of your highest or most intense emotion.

During each session you will be recorded while performing several tasks in random order:

1. Perform an individually chosen song that you have been practicing with your vocal instructor.
2. Sing the beginning section of "Caro mio ben" by Giordanni.
3. Sing isolated vowels /a/, /u/, and /i/ under several pitch and loudness conditions. This includes singing each vowel at a comfortable pitch, with three different intensities: low, medium and high. This also includes singing each vowel at a comfortable intensity, at three pitches: a low, a medium and a high pitch.

Risks/Discomforts
There are minimal risks associated with participation in this study. The equipment used in this study has been used previously with no adverse effects. You may initially feel uncomfortable performing with emotion in a recording studio instead of in front of an audience. If you have been very vocally active prior to your recording, it is possible that you may feel vocal fatigue. If this occurs, you may rest and if necessary, postpone your recording.

Benefits
Aside from a complementary summary of acoustic findings from the study, you will receive no direct benefits from participating in this study. The overall results of this study may lead to a greater understanding of the physiology of singing and contributions of emotion to the voice.

This study may provide valuable information regarding the relationship between expression of emotion in any type of performance, and qualities of voice and speech.

Confidentiality
An identification number instead of name will be used in storing and analyzing the recordings of each singer. Your name and other identifying information will not be used in print or electronic records of this study. Only summary data without reference to names will be reported when the study is complete.

Participation
Participation in this research study is voluntary. You have the right to withdraw at any time or refuse to participate entirely without any impact on your grades or your status at Brigham Young University, the BYU Music Department, or in any of its courses.

Questions about the Research
If you have any questions about this study, you may contact Dr. Christopher Dromey at (801) 422-6461.

Questions about Your Rights as a Research Participant
If you have questions you do not feel comfortable asking the researcher, you may contact Sandee Muñoz, IRB Administrator, at (801) 422-1461; A-285 ASB, Brigham Young University, Provo, UT 84602; irb@byu.edu.

Signatures
I understand what is involved in participating in this research study. My questions have been answered and I have been offered a copy of this form for my records. I understand that I may withdraw from participating at any time. I agree to participate in this study.

________________________________ __________________________
Signature Date

____
Printed Name