The Effect of Timbre, Pitch, and Vibrato on Vocal Pitch-Matching Accuracy

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Summary: Objective/hypothesis. This study seeks to examine how target stimulus timbre, vibrato, pitch, and singer classification affect pitch-matching accuracy.
Study design. This is a repeated-measures factorial design.
Methods. Source signals were synthesized with a source slope of −12 dB/octave with and without vibrato at each of the pitches, C4, B4, and F5. These source signals were filtered using five formant patterns (A–E) constituting a total of 30 stimuli (5 formant patterns × 3 pitches × 2 vibrato conditions). Twelve sopranos and 11 mezzo-sopranos with at least 3 years of individual voice training were recruited from the University Of Tennessee, Knoxville, School of Music and the Knoxville Opera Company. Each singer attempted to match the pitch of all 30 stimuli presented twice in a random order.
Results. Results indicated that there was no significant effect of formant pattern on pitch-matching accuracy. With increasing pitch from C4 to F5, pitch-matching accuracy increased in midpoint of the vowel condition but not in prephonatory set condition. Mezzo-sopranos moved toward being in tune from prephonatory to midpoint of the vowel. However, sopranos at C4 sang closer to being in tune at prephonatory but lowered the pitch at the midpoint of the vowel. Presence or absence of vibrato did not affect the pitch-matching accuracy. However, the interesting finding of the study was that singers attempted to match the timbre of stimuli with vibrato.
Conclusions. The results of this study show that pitch matching is a complex process affected by many parameters.
Key Words: Pitch perception–Vocal quality–Formant frequency–Vibrato–Timbre.

INTRODUCTION

There are many attributes that contribute to the development of a great vocal musician. One major factor is the ability to accurately match pitch. A survey of 1000 music educators revealed that they believed pitch intonation was the most important factor for determining singing ability, followed by timbre and musicality.[1] Although good pitch intonation is not sufficient alone for great vocal musicianship, it certainly is necessary.

The American National Standards Institute[2] defines pitch as that attribute of auditory sensation in terms of which sounds may be ordered from low to high. The primary acoustic correlate of pitch is fundamental frequency; however, intensity,[3–5] duration,[6–8] timbre,[9–19] and perhaps also vibrato[20] have been shown to affect the perception of pitch.

Numerous studies have found that timbre can influence the accuracy of pitch perception.[10,11,13–15,21,22] Research has suggested that stimuli with energy concentrated in the higher frequencies are perceived as being sharper than stimuli with energy concentrated in the lower frequencies.[17,19] To more specifically define under what conditions timbre can affect the perception of pitch, Singh and Hirsh[18] generated six types of stimuli with slightly different spectral energy concentrations. Generally, listeners perceived changes in energy concentration as changes in timbre and changes in F_0 as changes in pitch. However, when the F_0 change was small, <2%, spectral centroid change was the primary predictor of perceived pitch change. Singh and Hirsh[18] interpreted this to mean that when F_0 changes by <2%, pitch and timbre are integrally perceived. When F_0 changes by >2%, pitch and timbre are separable.

The perceived pitch of frequency modulated (FM) simple and complex tones is generally believed to be highly correlated with the linear average of the time-varying frequency. Sundberg tested this hypothesis with long-duration FM pure tones[23] and with synthetic complex tones[24] and found this to be true. Besouw and Howard[25] found no difference in pitch perception between FM sine tones and FM complex tones. However, Shonle and Horan[26] found perception of the pitch of a square wave to be unexpectedly lower than that of an FM sine wave, suggesting the pitch of FM complex tones might be perceived differently than that of FM sine tones.

Although the perception of pitch in FM stimuli has been fairly well studied, there are very few published studies concerning the ability of singers to accurately match pitch when the stimuli are complex vibrato tones. Yarbrough et al[20] found that kindergarten-aged singers with poor pitch control produced a significantly greater number of correct responses when the target complex stimuli contained no vibrato than when the target complex stimuli contained vibrato. It is unknown how or whether vibrato might interact with timbre differences to affect vocal pitch matching in adult singers.

The fact that timbre can affect pitch perception and pitch matching raises some interesting questions regarding pitch perception and pitch matching in singers. Traditionally, singing voices have been divided into categories on the basis of the classifications of bass, baritone, tenor, contralto, mezzo-soprano, and soprano. Although these categories are typically defined according to pitch range, they are also defined by specific vocal timbres. Researchers have suggested that vocal tract length, and

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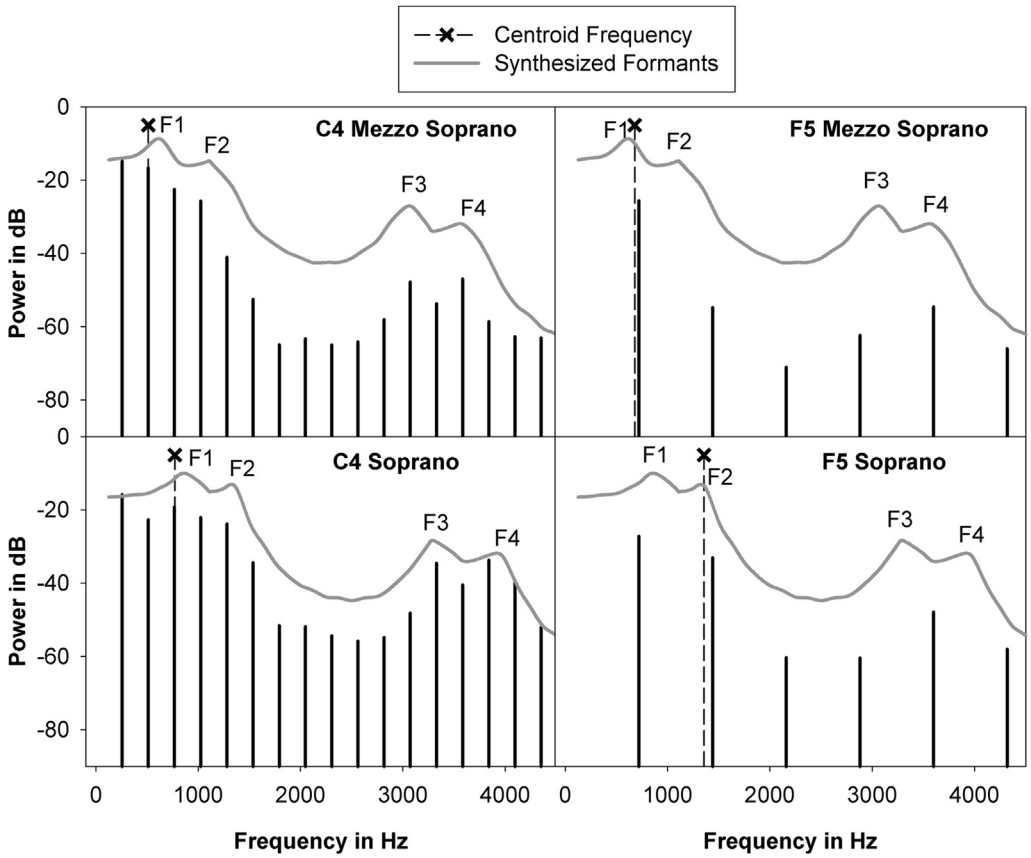

FIGURE 1. Formant frequencies, output spectra, and spectral centroid from a synthetic mezzo-soprano and soprano at the pitches C4 and F5.

therefore its corresponding effect on timbre, is one of the primary predictors of voice category.[27,28] Numerous researchers have demonstrated that formant frequency differences exist between the vocal categories,[27,29–33] with formant frequency values increasing in the order of bass, baritone, tenor, contralto, mezzo-soprano, and soprano. Thus, it is likely the case that spectral centroid, which is a measure based on the distribution of acoustic energy in the spectra, also increases in this manner. This relationship is illustrated in Figure 1.

Purpose of the study

Most studies in the present literature focus on the pitch perception and production abilities of poor singers.[20,21,34,35] However, minor pitch perception and production problems can have a devastating effect on highly trained professional singers who must face intense competition for jobs. The present investigation focuses on well-trained singers who, if they are inaccurate in pitch, are likely to produce small errors, to determine if the timbre of the vocal model influences their pitch-matching accuracy.

The present study seeks to answer the following questions:

1. Do classically trained female singers more accurately match pitch when the target stimulus has spectral information similar to their own voice type? On the basis of research showing pitch perception to be influenced by timbre,[10,11,13–15,21,22] we hypothesize that singers will find it more difficult to match pitch accurately when the target timbre is of a different voice category than their own.
2. Does the spectral centroid of the target stimulus affect pitch matching in a systematic manner on the basis of the singer's own spectral centroid? We hypothesize that singers whose spectral centroid is slightly lower than the target stimulus will hear the stimulus as being higher in pitch than their own productions and will adjust their fundamental frequency upward, whereas singers whose spectral centroid is higher than that of the target stimulus will hear the target as being slightly lower in pitch than their own productions and will adjust their fundamental frequency downward. Figure 2 illustrates these hypothetical responses. In this figure, the difference in cents between the target stimulus and the singer's production is represented on the y-axis. Positive values mean the production would be sharp (higher fundamental frequency than the target), whereas negative values mean the production would be flat (lower fundamental frequency than the target).
3. Does the ability to match pitch vary with increasing pitch? Because spectral centroid is a product of the interaction of source and filter, its location can vary greatly depending on how closely spaced the harmonics are and whether or not they line up with the formants (Figure 1). We hypothesize that the changes in formant resolution across pitch will affect pitch-matching ability.

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