

CHOIR ACOUSTICS:

AN EMPIRICAL APPROACH TO THE SOUND YOU WANT

James F. Daugherty, Ph.D.
Division of Music Education & Music Therapy
The University of Kansas
jdaugher@ku.edu

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ACOUSTICS:

▼
Production
Propagation
Perception
 of sound

CHOIR ACOUSTICS has to do with the production, propagation, and perception of choral sound, the composite sound of a multitude of vocal sound sources in ensemble

CHORAL SOUND:

- Has properties of both complex tones and very narrow-band noise
- Sonic character is that of a sum of sounds that are similar, yet not phase coherent
- Spectral peak (using long-time-average spectra) in the region of 500-700 Hz
- SPL of choral sound has large, random short-term variations due to beats

Chorus effect: occurs when many voices and their reflections create a quasi-random sound of such complexity that the normal mechanisms of auditory localization and fusion are disrupted; in effect, dissociates sound from its sources and endows it with an "independent" existence

Instability of F_0 (phonation frequency/fundamental frequency) produces flutter, a primary contributor to the chorus effect

- Room/venue acoustical properties are a major partner in choral sound; they either enhance or hinder the production, propagation and perception of choral sound
- In choral sound, the whole is more than the sum of its parts

An EMPIRICAL APPROACH is one dependent upon data obtained and analyzed according to canons of scientific research. It is not based simply on opinion, experience or informal anecdotal evidence.

VALUE STATEMENT: There is no universal "good" or "bad" with regard to choral soundscape.....only "different. " You, the teacher/conductor, get to decide.

DEFINITIONS:

sound = a perceived, aural psychological sensation produced by vibration

frequency = pitch; the number of vibrations per second, expressed in hertz (Hz); the number of cycles (complete vibrations) that occur in one second

Cent = unit of frequency ratio (1c = 0.01 (1/100) of a chromatic semi-tone; 1200cents= 1 octave); unit most commonly used to represent pitch deviation

fundamental = the mode of vibration (or component of sound) with the lowest frequency

partial = a mode of vibration (or component of sound); includes the fundamental plus the overtones; any component of the harmonic series including the fundamental

overtone = a mode of vibration (or component of sound) with a frequency greater than the fundamental frequency; any overtone will be higher than the fundamental frequency and a whole number multiple of it

formant = a range of frequency to which a system responds preferentially or which is emphasized in its output

singer's formant = a resonance of the vocal tract; appears around 2500-3000 Hz

vibrato = frequency modulation (FM) that may or may not have amplitude modulation (AM) associated with it; periodic undulation of fundamental frequency

F_0 = phonation frequency, also fundamental frequency

dB = decibel; a relative unit of measure used to compare the ratio of two quantities, or to express the ratio of one such quantity to an appropriate reference; as a unit of sound intensity, the decibel is a relationship between the sound being measured and a reference intensity upon which the sound level meter is calibrated

Hz = hertz; one hertz equals one cycle per second

beats = periodic variations in amplitude that result from the superposition or addition of two tones with nearly the same frequency; the periodic reinforcement and cancellation of two wave fronts with frequencies closer together than 20 Hz; above 20 Hz the beats will be perceived as a separate third tone (called a difference tone or combination tone)

masking = the effect of one set of sounds impinging upon the perception of another set of sounds; the process by which the threshold of audibility of one set of sounds is raised by the presence of another set of sounds

flutter = F_0 fluctuations that do not affect pitch

wow = unintentional F_0 fluctuations that affect pitch

scatter = the inter-singer dispersion in F_0 , measured as the ensemble standard deviation in $M F_0$ (the time average of F_0 over some duration of interest)

interval = a nominal frequency ratio defined by a musical scale

intonation = the frequency ratio actually used when rendering an interval

airborne feedback/Self = the sound a singer hears of his or her own voice

airborne reference/Other = the sound a singer hears of the rest of the choir

articulation = shaping of the vocal tract by positioning of lips, jaw, tongue, velum, larynx, etc.; as the throat and mouth change setting for different vowel and consonant sounds, they also change the harmonic content of the vocalization

SPL = sound pressure level

reverberation = the perceived phenomena of multiple echoes mixing with the primary sound; reflected choral sound is necessary to reinforce the complex primary sound of the choir, but if there are too many reflective surfaces in a venue, detrimental reverberation occurs

absorption = the trapping of sound waves in fibrous or porous materials thus weakening the wavefront by reflecting and diffusing sound energy

SOR=Self to Other Ratio (Ternström). A choral singer simultaneously hears airborne and bone conducted feedback from his/her own voice (Self) and the sound of the rest of the choir (Other). A positive SOR means that the sound of Self is a few decibels higher than the sound of Other. An average preferred SOR seems to be +6dB.

CHORAL SINGING VS SOLO SINGING:

Choral singing and solo singing are two distinctly different modes of musical performance, making different demands on the singers. Most research on the acoustics of singing to date has been directed at solo singing, and so less is known about voice use in choir singing, but our knowledge is growing.

- In choral singing, there is an emphasis on fundamental tones rather than partials
Rossing, et al (1986, 1987) found that bass/baritones and sopranos who are both solo and choral singers use a more pronounced singer's format and lower amplitude fundamental tone in solo singing. The emphasis on the fundamental in choral singing appears to be accomplished through adjustments in both articulation (adjustment of formant frequencies) and phonation (change in glottal waveform).
- Ford (2003) found significant preferences for non-resonant choral tone among undergraduate students, including those with choral training, those with instrumental training only, and persons with no training in either choral or instrumental music. Most subjects clearly preferred non-resonant (i.e., without singer's formant) choral tone. Moreover, choral training appears to increase such preference.
- Ekholm (2000) reported that voice teachers preferred a soloistic vocal production mode even in choral singing, while choral conductors preferred a more blended sound.
- In choral singing, there are frequent adjustments in intensity
Goodwin (1980) found that soprano singers use a softer voice and weaker higher spectrum partials when asked to blend with other voices
- Amateur choral singers of good ability have closer relationship of speaking and singing voices than professional soloists (Ternström, 1989)

CHORAL SOUND:

(Hunt, 1970) found that the unity /attractiveness of the choral vowel is essentially a matter of articulatory intonation and essential for perception of blend.

It is difficult to extend the dynamic range of a choir, especially toward louder sounds. Law of diminishing returns: doubling the number of choir singers only increases sound level by 3 dB (Ternström, 1989).

Analyses of recorded professional choirs reveal:

Major thirds are sung larger than in equal temperament (average 416c)

minor thirds are sung more narrowly (average 216c)

Octaves and especially fifths are sung very close to just intonation

(Lottemoser and Meyer, 1960; Lottemoser, 1969)

The masking effect of one's own voice in a choral situation is greater in low frequencies (Ternström, 1989)

Scatter in a bass section in an amateur choir with acceptable intonation was found to be plus or minus 13 cents, i.e., on average two-thirds of the singers were within one-eighth of a semitone from the group average (Ternström, 1989).

Choral singers exhibit the Lombard Effect (raising the intensity of their own voices in the presence of masking sound in order to hear themselves) (Tonkinson, 1990)

It appears that the intrinsic pitch of vowels, well documented in speech, is also a factor in choral singing and is exacerbated in the absence of feedback (Ternström, 1989)

Certain combination of vowels are potent pitch/frequency benders:

i e (as in kyrie eleison) can carry a change in F_0 of almost 35%

u vowel has a relatively low number of harmonics and is perceived to drop in pitch the louder it gets, and sharp with soft reference tones

front vowels (e.g., i and y) tend to raise F_0

ah vowel tends to lower F_0

(Ternström, 1989)

Sundberg (1987) speculates that while solo singers can check their tuning by a stable reference, such as piano or orchestral accompaniment, choral singers have only fellow singers who are fighting against the same vowel intonation tendencies.

There is a spectral bias in the feedback received from one's own voice in a choral setting. The feedback from one's own voice is greater in low frequency sound, because short waves (higher frequencies) do not diffract around the mouth to the ear as readily as longer waves (lower frequencies). (Ternström, 1989)

Effect of choir folders:

- Can serve as a sound reflector, increasing the airborne feedback of one's own voice, especially for higher frequency sounds

- Can serve as a sound absorber, giving a high frequency loss of 1-3 dB in the 2-10 kHz range

- Can serve as a sound booster, giving a boost of approximately 2 dB in the 200-500 Hz range

(Ternström, 1989)

If the choral reference sound is more than 5 dB louder than the feedback from one's own voice, intonation errors increase significantly. (Ternström, 1989)

Individual singers within the same choir, subject to the same choral training, can vary greatly in their vocal output power (Coleman, 1994).

Pitch-Amplitude Effect occurs with darker vowels with only a few low partials (e.g., u) and for sopranos singing high and loud. Basically, singers are likely to perceive their own voices as a bit flat and compensate by singing tones perceived as sharp by others (Sundberg and Ternström, 1988).

RESEARCH ON ROOM REFLECTION AND CHORAL SINGING

Reflected sound in a room contains two main parts: early reflections and reverberation sound. Early reflections arrive within 50 - 100 msec and are generated by sound-reflecting surfaces in the neighborhood of the choir. As the number of these reflections increase with time, they are gradually smeared into a continuous sound of decreasing level. This sound is called the reverberation sound. (Sundberg, 1987)

Marshall and Meyer (1985) found that ensemble singers prefer strong early reflections, provided they arrived within 40 msec. (This corresponds to a distance between the singers and a sound reflecting surface of up to 7 meters). The stronger such reflexes were, the more they were appreciated.

However, Marshall and Meyer (1985) also found that if the closest sound reflector was more than 7 meters away from the singers, then the loudness of the reverberation sound became more important than the early reflections. It did not matter very much if the duration of the reverberation sound was 1, 1.5, or 3 sec.

To some extent, choirs appear to adapt their sound level and voice usage to the room acoustics. Choral singers appear to use a higher laryngeal position and to oversing in more absorbent rooms, and in absorbent rooms, one's own voice can sound much louder to the singer (though not to the audience) than the sound from the rest of the choir (this is especially so for sopranos singing at higher frequencies, who will sing sharp in such circumstances without noticing it). (Ternström, 1989)

Sundberg (1987) speculates that room acoustics primarily influence the level at which singers hear the rest of the choir, yet may also effect an individual singer's intonation depending on how loud one hears one's own voice.

RESEARCH ON CHOIR FORMATION:

Empirical investigations measuring choral sound preference with respect to choir formation (sectional, mixed, etc.): Lambson (1961) and Tocheff (1990), Aspaas, et al (2004) using intact college choirs, Daugherty (2003, 1999, 1996a, 1996b), using intact high school and college choirs. Ekholm (2000) employed a group of college voice majors.

Results indicate either no significant auditor preference overall for either sectional or mixed formations, or a non-consistent overall preference for sectional formation.

Weaker singers prefer sectional formation; stronger female singers prefer mixed formation. (Daugherty, 1996a)

Choristers, especially males, appear to prefer to sing in the middle section of the choir and to eschew the back row, though stronger female singers may prefer the outer edge of the choir (Daugherty, 1996a).

Daugherty (1996b, 1999a) found that choristers, especially female choristers, preferred a mixed formation, while auditors tended significantly to favor sectional formation.

Daugherty (1999a) speculated that mixed formation is probably a poorly executed spacing phenomenon, i.e., the separation of voices that produce like frequencies.

The major finding of the Daugherty studies was that choir spacing, not choir formation, made the greatest contribution to preferred choral sound for both choristers and auditors. Preferences are related to spacing dimensions, not formation per se.

Daugherty (2000a) suggested that many strategies of choir formation per se are grounded in fallacious logic, e.g., the fallacy of composition and the fallacy of misplaced concreteness.

Daugherty (2003) found that random placement of singers in a twenty-member chamber choir was preferred by auditors more than a synergistic conductor devised placement of singers.

Aspaas, et al (2004) found no spectral differences in sound due to formation.

RESEARCH ON VOICE MATCHING IN A CHORAL CONTEXT

Weston Noble and Rodney Eichenberger, among others, employ methods of voice compatibility matching to achieve choral blend. Giardiniere (1991) attempted to investigate this phenomenon in relation to the procedures employed by Noble. The research, however, suffered from design inadequacies, and results were inconclusive.

Tocheff (1990) studied "acoustical placement" of voices, a researcher devised voice matching process and found that a positive effect for such ratings as blend, tone quality, etc. The research, however, evidenced major flaws.

Ekholm's (2000) research was also seriously flawed. She reported that an "acoustic" seating arrangement resulted in the highest evaluations of choral sound.

A primary difficulty in conducting empirical research on the phenomenon of voice compatibility matching is that there are, as yet, no objective criteria or standardization procedures for the process. Each conductor's method is largely idiosyncratic, i.e., not replicable by others.

In addition, there well may be a certain "power of suggestion" operative in such contexts.

Daugherty (1997, 2000b) reported there was pedagogical value to employing a process of such nature, regardless of any acoustic effect, because it presented (a) a means to focus a choir's attention upon its choral sound and blend; (b) a quick method of hearing individual choristers; and (c) a non-confrontational way to place unusual voices or behavior problems within the choir in a position of least influence.

Daugherty (2000a) theorized that voice matching procedures were likely related to the spacing apart of singers with incompatible vocal production characteristics.

RESEARCH ON CHOIR SPACING

Types of choir spacing (as defined by Daugherty, 1996b):

Close, Lateral, Circumambient.

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X X X X X X X X X X X X X
X X X X X X X X X X X X X
X X X X X X X X X X X X X

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Close

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X X X X X X X X X X X X X X X
X X X X X X X X X X X X X X
X X X X X X X X X X X X X X

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Lateral

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X X X X X X X X X X X X X X X
X X X X X X X X X X X X X X
X X X X X X X X X X X X X X

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Circumambient

95%-100% of singers in choirs employed report that choir spacing has a positive influence on ensemble sound. Singers attribute to spread spacing more independent singing, improved vocal production, and ability to hear better both self and ensemble (Daugherty, 1996b, 1999a, 2003).

Auditors report significant and consistent preference for singing with spread spacing.

Auditors express preference for sectional formations with spread spacing over mixed formations with less spread spacing.

Weaker singers tend to prefer lateral or close spacing; average and stronger singers tend to prefer circumambient or lateral spacing.

Daugherty (2000b) posits that choir spacing has both physical and metaphysical meanings, and that the philosophical dimensions of choral space raise important aesthetic, sociological/multicultural, and economic questions. He suggests, for instance, that the invention of the portable choral riser is a physical manifestation of the aesthetic concept of choral sound as an "art object" separated from contextual experience.

Daugherty (2003) found that male singers (tenors and basses) in a twenty-member chamber choir sounded best with lateral spacing, while female singers (sopranos and altos) sounded best with circumambient spacing.

RESEARCH ON SELF-TO-OTHER RATIO (SOR):

Naylor (1987) was the first to introduce a formal definition of "hearing-of-self" and "hearing-of-others" in conjunction with research into instrumental ensemble sound.

Early studies by Sundberg and Ternström found that the level of sound choristers hear from the rest of the choir may vary within a rather wide range without causing intonation problems. However, when choral singers cannot hear their own voices, the situation becomes rapidly chaotic.

Ternström (1989, 1994, 1995, 1999) developed and analyzed the Self-to-Other Ratio (SOR), an abstract measurement of SPL obtained by factoring in absorption/reverberation of the room and obtained in earlier studies (1989, 1994, 1995) from individual singers via binaural microphones calibrated for SPL and worn in the outer ears during live choral singing, more recently (1999) from SOR preferences determined by using a synthesized choir as reference.

For choirs of two or more rows:

- Lower SOR obtains in the center of the choir
- Higher SOR obtains at the sides of the choir

Sopranos tend to have higher SOR (Sopranos sing louder than other voices, since vocal power increases with phonation frequency)

Basses tend to have lower SOR

Tenors and Basses prefer a somewhat higher SOR on upper F_0 than lower F_0 .

Within choirs, averaged SORs can vary over 6 dB

The masking effect of one's own voice is greatest in low frequencies.

Using Ternström 's method, Daugherty (1996b) found that the SOR for a male baritone was lower in close section formation and higher in lateral spread formation (difference was about 4 dB). He also found that SOR for a female soprano was lower in close section formation and higher in lateral spread formation (difference was about 2.5 dB).

The reference sound of the choir and room reflections of one's own voice are not in phase at all frequencies as they arrive at the singer's ears (Ternström, 1999).

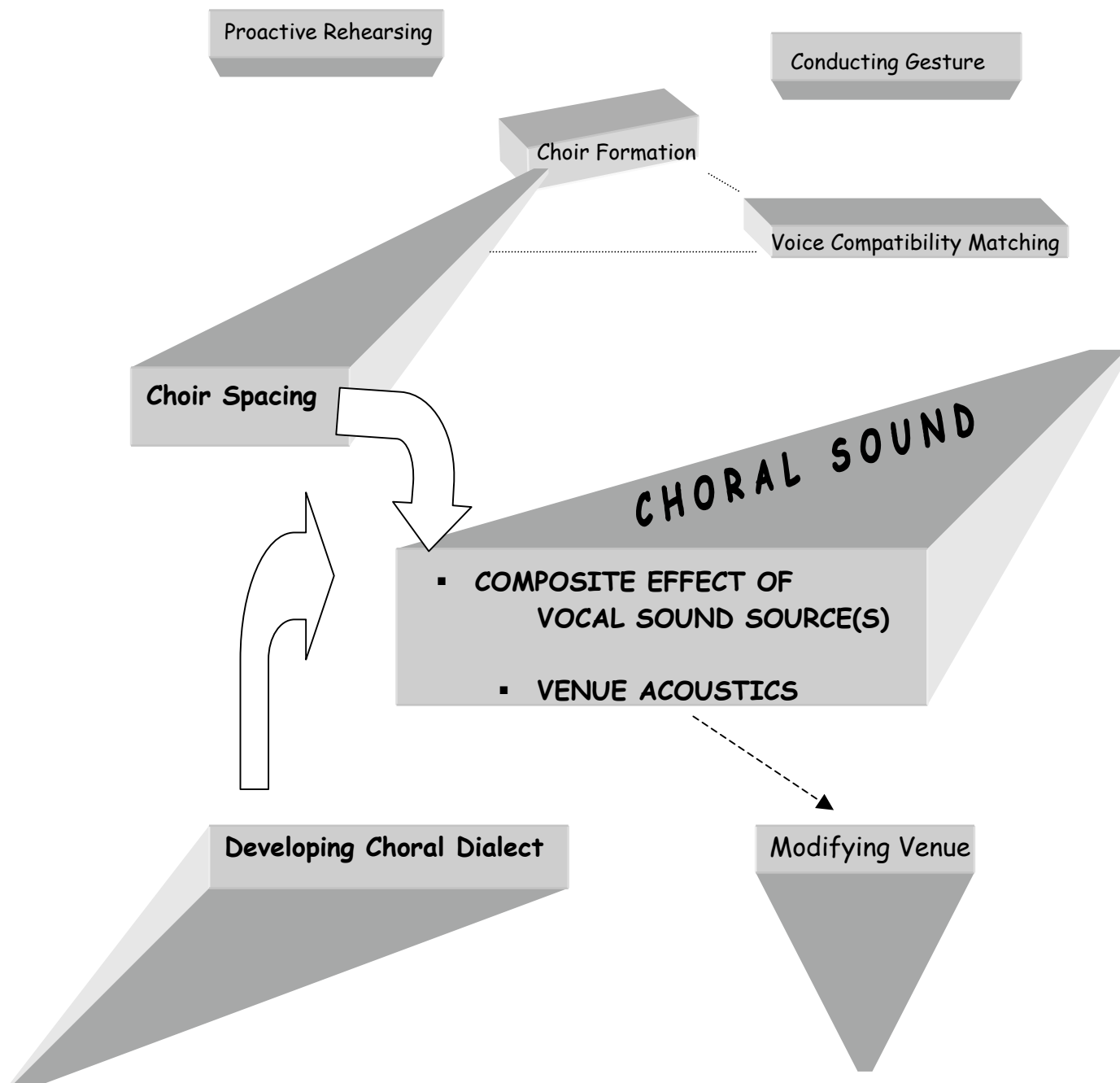
Ternström (1999) speculates that SOR preferences may, at least in part, be acquired, i.e., influenced by choristers' customary/preferred positions within the choir.

SOR increases (a) when room absorption increases, (b) when spacing increases, and (c) when the number of singers decreases (Ternström, 1999).

CONDUCTING GESTURE & CHORAL SOUND

Rodney Eichenberger and others have suggested that for the choral conductor “What They See Is What You Get.” Empirical research to examine what effect, if any, type and size of conducting gesture has on the choral sound of an ensemble is just beginning. Two studies to date (Fuelberth, 2003, 2004) found that certain conductor gestures do produce the perception of vocal tension among choral singers, while other gestures do not.

BUILDING CHORAL SOUND



The sound of your choir is most influenced acoustically by

(a) its composite of choral sound sources/singers;

and, particularly, (b) the venue in which the choir sings.

These factors, in turn, can be influenced somewhat by:

- Developing the "choral dialect" of your ensemble (enhancing the composite production quality of your singers as much as possible given their instruments and interest) via

Consistent and purposeful group voice building that emphasizes:

- ✓ Developing the lighter mechanism by vocalizing from the top down
- ✓ Uniform vowel formation and modification
- ✓ Proper balance between feedback & reference sounds
- ✓ Sequenced warm-ups
- Effecting whatever material modifications are possible to the rehearsal and performance venues

Thereafter, nuances in choral soundscape can be achieved by:

- Choir spacing
- Voice Compatibility matching/Placement
- Conducting Gestures as they impact vocal production
- Proactive rehearsing

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