A Comparative Analysis of Techniques of Euphonium and Vocal Performance Using Acoustical Properties

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UNIVERSITY OF MIAMI

A COMPARATIVE ANALYSIS OF ARTICULATION TECHNIQUES OF EUPHONIUM AND VOCAL PERFORMANCE USING ACOUSTICAL PROPERTIES

By

Brian Logan

A DOCTORAL ESSAY

Submitted to the Faculty of the University of Miami in partial fulfillment of the requirements for the degree of Doctor of Musical Arts

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A Comparative Analysis of Techniques of Euphonium and Vocal Performance Using Acoustical Properties

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After researching that many brass pedagogy texts make allusions to vocal performance as the ideal standard, this essay observed the ability of the euphonium performer to create different articulation sounds. Comparisons between voice and brass articulations were made. The effectiveness was determined by comparing pertinent acoustical components of brass methods to that of a single vocalist. To begin, this study catalogued preeminent suggested techniques for performing brass articulation found in method, pedagogy, magazine, and personal memoir texts. These techniques were collected into a list and given to a euphonium player subject from the University of Miami. In an anechoic chamber, the subject was given the instructions to perform the articulation techniques previously compiled from the literature. Audio was collected by a single Earthworks M50 Reference Microphone connected to a Merging-Morus PreAmp at a 48kHz sample rate. The microphone was placed at a radial distance of one meter from the bell. A recording sample was only accepted when the subject and researcher believed the subject was able to efficiently accomplish the provided directions. In the same chamber, with the same microphone, a lone vocalist was recorded with the same microphone placed also at a radial distance of one meter. Recordings were then
normalized to the same amplitude to ensure that comparisons between individual
instrumentalists and the vocalist were possible. Transient qualities of articulation and
vocal onset were assessed using quantitative and qualitative methods. 1. Quantitative:
analyzing the general shape of the attack envelope. 2. Qualitative, measuring and
calculating a mathematical linear slope between the rise in decibels to the point of steady
state in the envelope over the duration of time. Additionally comparing the harmonic
composition of the attack envelope using comparison of the allotment of harmonics from
a Fast Fourier Transformation (FFT). Findings grouped articulation techniques and
phonemes together. Values were interpreted and arranged displaying techniques of
findings on two continuums. One, addressing the abrasiveness of the articulation and
propagation of sound, arranging the set of values from “hard” to “soft.” The second,
arranging the techniques and phonemes based on the harmonic content, or timbre, from
“dark” to “bright”. Results suggest inclusion of breath attack as a legitimate means of
articulation. Comparison of euphonium and vocal phoneme articulation showed that the
contact point of the tongue did not correlate to acoustical data. For example, labial
articulation in euphonium did not relate to labial articulations in voice; articulations of
the euphonium player using the blade of the tongue against the velar region (dorsal
articulation) did not correspond to phonemes where the blade of the tongue makes
contact with the velar region (phonemes /k/ and /g/).
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CHAPTER I: INTRODUCTION

The valved-brass family of instruments is a relatively modern instrument group compared to woodwind and string families. Thus the repertoire and pedagogy had less time to evolve and develop. The euphonium, the youngest of all brass instruments, has the smallest repertoire compared to other classical instruments.\(^1\) As a result, generations of euphonium players have supplemented the repertoire with transcriptions of solos from other mediums. Because string transcriptions are often non-idiomatic for brass, featuring melodies with many large leaps and an expansive range, euphonium players have more frequently turned to transcribing vocal works to expand repertoire.

Like many new instruments, performances featuring the euphonium have struggled to break into the classical performance repertoire canon. In the mid-nineteenth century, illustrious brass pedagogue Jean Baptiste Arban wrote of this phenomenon saying that even new instruments such as the cornet were treated with “supreme indifference”.\(^2\) He claimed that this phenomenon recurred with each new invention, and can be applied to new saxhorns like the euphonium.

**Need for Study**

In the absence of original compositions, many euphonium performers borrowed compositions intended for other instruments or for voice. Sharon Huff wrote that the euphonium did not exist during the time when many compositional masters wrote.

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Because of this omission in the literature, the euphoniumist frequently borrows literature originally written for the bassoon, cello, trombone, and trumpet. Huff compiled a comprehensive list of transcriptions that list vocal works by “Mozart, Bizet, Puccini, Rachmaninoff, Fauré, Schubert, and Rossini”. This suggests that the euphonium repertoire has been greatly supplemented by transcribing iconic vocal arias and art songs from the vocal repertoire.3

The discography, which features the euphonium as a solo instrument, often includes numerous transcriptions of songs and arias. Although this collection of recorded euphonium solos does not consistently include dates, which would determine whether or not this portion of the repertoire has changed over the centuries, it does demonstrate the volume of recordings of vocal repertoire that have been published. British virtuoso Steven Mead has published albums such as Bella Italia featuring arrangements for solo euphonium and wind band performing Italian song and aria transcriptions.4 In New Zealand, Australian performers Riki McDonnell and Mike Kilroy have released multiple albums of arias and scenes from well-known operas arranged for brass band and euphonium solo/duet.5 In America, contemporary albums such as Demondrae Thurman’s Songs of a Wayfarer contain transcriptions of vocal works from Classical and Romantic songs and arias.6 Also in America, military band euphonium players, such as Michael Colburn have recorded Puccini arias.7 Lastly, Dr. Brian Bowman in his album Sacred

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5 Riki McDonnell and Mike Kilroy, Operatic Euphonium, Grimethorpe Colliery Band, Conducted by Garry Cutt, Polyphonic Reproductions LTD. QPRL 072D, 2008, CD-ROM.
6 Demondrae Thurman, Songs of a Wayfarer, Summit Records 556, 2011, CD-ROM.
Euphonium recorded well-known sacred songs from the Christian church arranged for euphonium and piano. This suggests that the euphonium has relied heavily on transcribing works from the vocal repertoire for performance.

Although the prominence of the euphonium as a solo instrument has grown, it is without question that traditional solo instruments overshadow the euphonium. Orchestras in the United States, including the Boston Symphony Orchestra, New York Philharmonic, and Philadelphia Orchestra have never invited an euphoniumist as a soloist. In fact, a euphoniumist did not perform as a soloist in Carnegie Hall until 1976.

Through the volume of listing of euphonium compositions and transcriptions, the Guide to the Euphonium Repertoire exemplifies a substantial repertoire for euphonium. However, there is still a calling among euphonium players for repertoire of higher quality. Well known euphonium pedagogue and soloist, Leonard Falcone, criticized the music written for euphonium in the virtuosic era as being trivial and technique based. He wrote that the “forms, musical ideas, and the manner in which the material has been handled leaves much to be desired”. Falcone believes that compositions for brass instruments have devolved into a display of gymnastics. He adds that the baritone’s natural singing voice is what composers should write for as they do for voice or cello!

Multiple brass and euphonium competitions, such as the Leonard Falcone International Euphonium and Tuba Festival and the Lieksan Vaskiviikko in Finland, now commission

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8 Brian Bowman, The Sacred Euphonium, Mark Records 3788, 2004, CD-ROM.
works for competitors to perform to support the growth of new repertoire. Again, there is a desire and foundation to expand the repertoire with compositions that emulate the vocal idiom.

Composers have used the trombone since the classical era to double vocal lines in requiems and operas by Gluck and Mozart. Later, Berlioz, Wagner, Brahms, Tchaikovsky, Hindemith, and Rimsky-Korsakov utilized this association by composing trombone parts that introduce or emulate vocal lines. The most recent edition of the Arban method book for trombone and euphonium contains an extensive section on the art of phrasing. This includes melodies from famous arias and art songs by composers such as Bellini, Verdi, Schubert, and Beethoven.

From a pedagogical view, there is an intertwining of brass performance with vocal standards. In addition to the abundance of transcribed repertoire for euphonium and recorded discography, the repertoire of method books and pedagogical materials frequently reference sounding like a vocalist as a desirable quality. The pedagogy that references a singing approach falls into two categories. The first idolizes vocal performance standards and seeks to emulate the production of brass instruments in a way that most corresponds. The second advocates a singing approach that represents an unimpeded approach to performing where the instrumentalist elicits the exact melodic sounds (i.e. song) that are mentally conceived.

12 George Duerksen, “The Voice of the Trombone,” The Instrumentalist, 77 no. 1 (October 1964): 76.
13 Arban J.B., Brian Bowman, and Joseph Alessi, Complete Method for Trombone & Euphonium - Arban (Maple City, MI: Encore Music Publisher, 2000), 305.
Victor Kress, former teacher of Brass Instruments at San Francisco State College and member of the San Francisco Symphony Orchestra, teaches his students by asking them to sing a passage. He asks them to form the lip embouchure around the vowel used to sing. He adds that the brass instrument should sound “in sympathy” with the “vocal folds”.14 Making further comparisons to vocal pedagogy, Kress writes that, like a vocalist, “any change in the position of the throat, lips, tongue, teeth or mouth alters the tone or voice. Any movement should be kept to a minimum”.15 Principal Bass Trombone of the Chicago Symphony, Charlie Vernon, wrote a method book predicated upon achieving a singing voice through the bass trombone.16 Similarly, euphonium soloist Raymond Young advocates using a vibrato that is “the type used by vocalist[s]”.17 Another euphonium soloist, Harold Brasch, idolizes vocal standards in his teaching by claiming that the aim for legato is “to play a song or lyrical passage exactly as it would be sung by a competent vocalist”. Angela Winter advocates teaching beginning horn students baroque vocal arias to introduce them to the genre and give them artistic means of advancement. For example, Winter writes that:

The consonants, vowels, and syllables tell us both when to articulate, how, and to what degree. After reading the text, one should examine it as a vocalist would in its original layout – with the syllables placed under the melody… A hard consonant (t,b,d,k,p) requires a firm and clear articulation whereas a softer consonant (h,l,m,n) indicates a softer tonguing.18

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15 Ibid., 101.
17 Raymond G. Young, "Euphonium -- Well Sounding," *The Instrumentalist*, 18 no. 8 (March 1964), 73.
Winter writes that a consideration for different articulations must be made. However, the acoustical qualities of these considerations are undefined and no specific methods of performing a firm and clear articulation versus a softer articulation are provided.

The second pedagogical category again advocates a singing approach that advocates an unimpeded application of performing. At the 1995 International Brassfest in Bloomington, Indiana, brass pedagogue Arnold Jacobs explained that “85% of the intellectual concentration” of the performer is the “song” that exists as the impetus inside the performer. Trumpet pedagogue, John Haynie, similarly focused on the intent of having a song in mind when he wrote of his experience playing trumpet transcriptions of vocal hymns in church. Haynie sought to make “vocal copies of words” or lyrics he knew of the songs or hymns, by experimenting with articulation techniques and letting the “tongue do whatever it wanted to do in emulating the attacks used in saying the words”. William Whybrew wrote a Singing Approach to the Brasses. This text similarly teaches that brass players should practice singing the tone, then practicing a consistent and full flow of sound in order to achieve a singing approach. This method is intended to create more organic phrases, correct overblowing issues, and produce a more desirable tone quality.

Additionally, others have explored the relationship between voice production and brass production. Chistine Mounger wrote that “is is evident...that there is a potential

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connection between how one speaks and how one naturally plays the trombone”. 22 Although Mounger did not analyze quantitative acoustic data, she compiled a list of the 500 most common phonemes for English, German, and French languages, and statistically compared them to discover if one language concentrated more heavily on one vowel placement. Although the quantitative part of her study suggests there is a no connection, the qualitative section, which compared samples of recording, alludes to the possibility that language, and thus the mechanics of producing certain phonemes, does have an impact on the trombonist’s sound. 23 Similarly, Katie Cox sought to determine whether measurable and perceptible difference between American and British trombonists exist. Cox also determine whether any of these measurable differences correlate in any way with established differences between American English and British English speech. 24 Although Cox compared quantifiable acoustic parameters between British and American trombonists such as harmonic compositions and transient envelopes, she did not vary or define the specific articulation techniques used by the performing subjects. These examples further suggest that there is a connection between linguistic or vocal articulation and brass articulation that requires further exploration.

23 Ibid., 83.
Statement of Problem and Purpose

While consistently idealizing producing a brass sound and style that emulates the human voice, method books have suggested different techniques for articulation. There is a wealth of vocal transcriptions for brass instruments and an intertwining of vocal pedagogical concepts and standards to brass pedagogy. There are studies separately analyzing the acoustic qualities of the voice and brass instruments, and studies analyzing physical manipulations of performing various brass instrumental performance techniques and vocal techniques. The problem is that there are no studies that compare the acoustic qualities of brass articulation techniques with the acoustic qualities of the voice. The purpose of this study is to quantitatively and qualitatively analyze the acoustic manipulations of brass instrumental articulation performance techniques and acoustic qualities of articulation within the human voice.

Parameters of Study

In the second half of the twentieth century, scientific advancements allowed for greater analysis of the physical manipulations inside the mouth and throat of instrumentalists and singers. Additionally, acousticians were able to analyze the sound components of each family of instruments and of vocalists. After 1960, technological developments facilitated more precise analysis of timbre and amplitude. James Fourier’s

mathematical algorithm\textsuperscript{29} was furthered by James Cooley and John Tukey, facilitating an accurate intensity reading of specific frequencies in a sound.\textsuperscript{30} This allowed acousticians to analyze the overtone components for a sound elicited by various instruments and voices. A variety of studies analyze the acoustic qualities of voice and instruments separately.\textsuperscript{31,32}

Additionally, with technological advancements in high-speed visual analysis, many studies have assessed the physiological motions and changes that occur inside the mouth and throat when brass instrumentalists perform. These studies revealed that different physical movements or performance techniques yielded different sound qualities; however, the studies did not analyze the quantitative qualities of the sound and only asserted qualitative judgement on performance.

John Haynie conducted the first major study of its type by using a fluoroscopic video to observe the manipulation of the throat and tongue of both amateur and professional trumpet performers.\textsuperscript{33} After Haynie’s groundbreaking study in 1968, many researchers conducted derivative studies using other instruments. Kenton Frohrip also used video

\textsuperscript{29} The mathematician Fourier proved that any continuous function could be produced as an infinite sum of sine and cosine waves. His result has far-reaching implications for the reproduction and synthesis of sound. A pure sine wave can be converted into sound by a loudspeaker and will be perceived to be a steady, pure tone of a single pitch. The sounds from orchestral instruments usually consists of a fundamental and a complement of harmonics, which can be considered to be a superposition of sine waves of a fundamental frequency $f$ and integer multiples of that frequency.

$$s_p(t) = \sum_{k=-\infty}^{\infty} S[k] \cdot e^{2\pi ik t} \rightleftharpoons \sum_{k=-\infty}^{\infty} S[k] \delta \left( f - \frac{k}{P} \right).$$


\textsuperscript{33} John Haynie, \textit{A Videofluorographic Presentation of the Physiological Phenomena Influencing Trumpet Performance} (Denton, TX: North Texas State University School of Music, 1968), 7.
imaging techniques to analyze the manipulations of the jaw, lips, tongue, and throat in subjects performing trombone exercises and techniques.\textsuperscript{34} Like Haynie’s study, Frohrip’s study showed the differences of physical manipulations, but did not provide any quantitative acoustical data, which would suggest the efficiency or validity of a technique in producing a sound product. Similar studies have analyzed the anatomical manipulations of the glottis, throat, and vocal folds, and the created pressure changes above and below the glottis.\textsuperscript{35,36,37,38,39,40}

Different physical manipulations of the brass performer affect the sound product. In addition, pedagogues often describe emulating vocal performance as an ideal standard for brass performance. Thus, an effective comparison of the sound qualities of brass articulation and vocal onset will assess the effectiveness of these brass techniques. This study will focus on only one technique in brass instrumental performance and vocal performance: articulation.

The acoustical comparison must address relevant aspects. For example, analyzing the sound pressure (decibel) of the body of the note would not formulate an accurate

\textsuperscript{37} Yasuo Koike and Minoru Hirano, "Glottal-area Time Function and Subglottal-pressure Variation," \textit{The Journal of the Acoustical Society of America} 54, no. 6 (1973).
comparison of articulation, nor would comparing frequency compositions alone of recorded sounds. The differences in the “distribution of sound energy in the steady state frequency spectrum” is a key element in differentiating timbres; thus, there would be a defining difference in the frequency envelope of a brass instrument and a vocalist eliciting the exact same fundamental frequency.\textsuperscript{41}

In acoustics and audio realms, a transient is defined as a short-duration signal that represents a non-harmonic attack phase of a musical sound or spoken word.\textsuperscript{42} It contains a high degree of non-periodic components and a higher magnitude of high frequencies than the harmonic content of that sound. The transient, its harmonic composition, and the extent to which the higher components in the onset transient are synchronized with the growth of the lower components, are two of the main qualities responsible for determining and differentiating timbre.\textsuperscript{43} A 1967 study compared the tone colors of brass instruments by analyzing the quality of the transient.\textsuperscript{44, 45} A survey study processed the recorded sounds of instruments, in which the transient was removed, found that listeners were significantly less able to identify the instrument, further suggesting that the transient is an integral timbral component.\textsuperscript{46} This suggests that comparison of the sound qualities

\textsuperscript{42} Ibid., 42.
\textsuperscript{43} Ibid., 160.
\textsuperscript{44} Luce, David, and Melville Clark, Jr. "Physical Correlates of Brass-Instrument Tones." \textit{The Journal of the Acoustical Society of America} 42, no. 6 (1969): 1232-243. This study cited previous studies in determining that the identifiability of a musical instrument is resistant to frequency (pitch), amplitude (dynamic) particular instrument played of a given type (equipment) and instead relied heavily on the comparative quality of the attack transient in analyzing non-percussive orchestral instruments.
of articulation should be accomplished by focusing on the defining parameters of the transient.

**Research Questions**

In order to quantitatively and qualitatively analyze the acoustic manipulations of various brass articulation techniques with the acoustic qualities of articulation within the human voice, a comprehensive list of brass techniques prescribed for articulation is required. This study will address the following research questions:

1. What techniques for brass performance were advocated in method, pedagogical, and relevant texts for performing articulation?

2. Discussion of accepted articulation techniques present in method, pedagogical, and magazine texts.

After compiling these techniques, this study will assess:

3. What are the transient qualities of various brass articulations and vocal articulations (i.e. onsets)?
   
   i. What qualitative comparisons can be made between the attack envelope of various instrumental brass techniques and vocal phonemes?

   ii. Can a quantitative measure be used to describe, define, and/or correlate brass articulation techniques and vocal phonemes?

   iii. Are there any defining characteristics of the harmonic composition of the attack transient that describe, define, and/or correlate brass and vocal articulation?
Applications of Study

Applications will suggest that new and varied techniques in brass performance are effective in replicating vocal sounds. In all performance mediums, instrumentalists are required to blend articulations and timbre with various musicians or groups, e.g. woodwinds, other brass, piano, strings, etc. Illuminating the acoustic effect of various brass articulation techniques will allow future brass performers to choose appropriate techniques that allow them to successfully blend or mimic various instrumental or vocal musicians with whom they are performing.

Creating sounds that more accurately mimic vocal technique, style, and variety could increase the popularity of performances of brass instrumentalists performing vocal transcriptions. Maurice Faulkner advocates “developing every instruments’ capacity to the fullest”.47 Similarly, Howard Deye writes that:

Skillful use of the tongue also has a great deal to do with interpretation. Methods of attack are as important to the wind instrument player as types of bowing are to the string player.” Not only does the action of the tongue vary for different styles, and according to what register is being played on a single instrument, but it also varies between instruments. It is essential, then, that teachers of wind instruments acquaint themselves with these fundamental differences.48

A wider audience could further appreciate the variety, attention to detail, and nuance that this study will uncover. Conductor Hermann Scherchen advocates using techniques such as widening the acceptable uses of articulation. For example, Scherchen recommends using breath attacks for legato entries,

48 Howard Deye, "The Use of The Tongue," The Instrumentalist 1 no. 7 (March 1947): 21.
instrumental patterns merging into one another, and in order to introduce rest like interruptions within the course of a soft “portato”. This study does not suggest always using an articulation technique that corresponds to the phoneme used in a vocal transcription. However, knowing and defining the effects of various brass articulation techniques, and how they relate to the voice can inform and shape the musical decisions made by the performer.

This study will also impact pedagogy. John Haynie’s study found that players “improved by observing and imitating the action of the tongues of the finest players”. Students participating in Haynie’s videofluorographic analysis study improved from observing and subsequently attempting to mimic the physical manipulations of the tongue of professional brass instrumentalists. Thus, it is hypothesized that students observing and mimicking fundamental pitch modulation or transient qualities of professional vocal artists will also yield positive performance gains.

Lastly, the purpose and methods used in this study can be an introduction and research template for derivative studies seeking to ascertain the direct acoustical effects of other techniques. Further research could lead to codifying techniques to blend euphonium with other instrument groups. This study is intended to be replicated with greater sample sizes, as well as with other performance techniques in brass, woodwind, and string instruments.

Delimitations of Study

This study elects to analyze only one technique within brass pedagogy: articulation. Further studies could compare the acoustics of varying techniques in embouchure and aperture composition, legato, vibrato technique, oral cavity, breath support, range, flexibility, releases, or instrument equipment within brass instruments to the voice. An additional study may choose to analyze varying vocal techniques.

In this study, the sample size of brass instrumentalists is limited to one. This negates the variable of varied pedagogical backgrounds. Suggestions on brass pedagogy of a definitive nature would need a much larger sample size ranging in age, proficiency levels, geographical locations, and pedagogical backgrounds. Conversely, broad statements about the acoustical qualities vocalists have would also need a much larger and more varied sample group. Articulation qualities differ between vocalists from different nationalities; therefore, specializing in different languages would have subtly different methods of enunciating. An additional consideration would be made for collecting acoustic data in a controlled environment versus a performance setting. For example, the vibrato rate of an individual instrumentalist and/or vocalist may differ within the individual performance style of different repertoire.\textsuperscript{52} Differences between how performers articulate in a performance setting may also be different from articulations used on isolated phonemes in a recording studio.

\textsuperscript{52} Carl E. Seashore, Harold Seashore, and Joseph Tiffin, "Summary of the Established Facts in Experimental Studies on the Vibrato up to 1932," in \textit{The Vibrato} (Iowa City, IA: Iowa City Publishers, 1932).
This study will not verify that the physical changes requested in the performer are actually accomplished. As detailed in Chapter 3, recordings will be accepted into the study when the subject believes they accurately accomplished the requested technique. Misleading information may exist, as in Christopher Poole’s dissertation essay that sought to analyze the role of the larynx in bassoon vibrato. Subjects were asked to isolate vibrato to the jaw and it was determined that inadvertently the larynx still proved a major mechanism in vibrato production in all subjects. As a result, subjects may wrongly believe they are performing the task asked of them. However, because this study is intended to have pedagogical impacts, the effect of the requested change is still of note. Whether or not the subject is physically accomplishing the desired task or not, if the sound characteristics change in a desirable way, the objective of the teacher is achieved.

Further studies may compare the acoustic qualities of specific brass techniques to acoustic qualities of other instrument groups that often perform with brass instruments such as strings, keyboards, and woodwinds.

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CHAPTER 2: LITERATURE REVIEW

The purpose of this study is to quantitatively and qualitatively correlate the acoustic quality of articulation techniques used in performing the euphonium with acoustic qualities of the human singing voice. In order to comprehensively summarize and list brass techniques for performing articulations, a review of method and pedagogical texts for all brass instruments is required. Additionally, legato, the technique of playing seamless notes, is often referenced as an articulation style; thus, legato techniques will also be catalogued. Because this study uses the qualities of the voice as a constant, (e.g. free from varying performance techniques) an understanding of vocal method and pedagogy texts is necessary to accurately assess the ideals of performance practice in achieving onset and articulation. Additionally, for the purpose of this study, scholarly analysis of the acoustic compositions and variances of brass and vocal performance is consulted. The observation techniques of these acoustical studies will be used for analyzing general acoustic characteristics of voice and brass instruments separately. These techniques will assist in developing methodology for observing and measuring the spectral changes of sound components. The acoustical data from this study will correspond to the data from previous studies.

Brass Performance Methodology and Pedagogy

Originally published in 1864, cornet virtuoso Jean Baptiste Arban’s Complete Conservatory Method for Trumpet is the first brass method book published, and is respected and utilized throughout the twentieth and twenty-first centuries.\textsuperscript{54} Arban
observed that many cornetists have some isolated great technical qualities, but none were complete masters of all facets. His compilation of methods was intended to direct cornetists to acquire all necessary techniques. Arban intentionally provided sporadic and brief annotations. Instead of providing technical annotations of the physical requirements for achieving techniques, he believed it was more advantageous to include numerous exercises, suggesting that students should work through difficulties in practice. Arban’s methods were similar to other virtuosi cornetists who also compiled grand method texts.

At the time Arban wrote this text, the primary function of the cornet and other brass instruments was to perform virtuosic theme and variation solos. Leonard Falcone criticized the musical simplicity of this era, writing that “the creative work for brass instruments has been left entirely to the virtuosi of these instruments” and adds that “musical ideas, the forms, and the manner in which the material has been handled leaves much to be desired”. It is no surprise that Arban’s extensive collection of methods focuses heavily on virtuosity. Large sections of scales, arpeggios, ornaments, trills, articulation, and multiple tonguing, dwarf the amount of exercises on legato playing, slurs, or melodic efficiency. Emblematic of method books of the time, Arban sporadically left concise notes for the exercises. Although the musical material is thorough, it does not

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offer suggestions for what students should do if they are unable to complete or master the exercises.

Arban suggests that to begin making sound one must “strike” the sound by pronouncing the syllable “tu” (/tu/). Although Arban writes the tone should be “well struck” by a “proper tension of the lips,” he again, did not detail or describe what physiological mechanics inside the mouth must occur to produce this desired syllable of “tu”. Nor does Arban describe how to create a “proper tension of the lips”. Arban briefly discussed the slur as the method of changing between notes “without the interruption or aid of the tongue” as it applies to legato playing.

In the era of virtuosity texts, several significant method books follow Arban’s template. Methods provided little or conflicting information on how to accomplish these tasks. In the method book by Luis Saint-Jacome, Jacome writes on articulation: “the tongue is used to start and separate the notes”. He later offers slightly more detail than Arban on an initial articulation, writing that instrumentalists should “place the tongue against the upper teeth and articulate the syllable, ‘tu,’ jerking the tongue back quickly and blowing through the lips at the same time vibrating the lip”. This is the first written account of how a performer should physically configure his/her tongue to accomplish an articulation on a brass instrument.

If one uses the tongue to separate notes, as the Saint-Jacome suggests, one must create a second seal with the tongue. This creates a hard syllable at the front and end of

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59 Arban, Arban’s Complete Conservatory Method, 1.
60 Ibid., 37.
61 Saint-Jacome, Grand Method for Cornet, 3.
the syllable (the phoneme for this articulation would be /tut/). This method of articulation is later rejected and is inconsistent in Saint-Jacome’s own annotations, who suggested the phoneme “tu” (/tu/) for articulations. As with the Arban method, Saint-Jacome offers no annotation on how the student should execute a slur and does not provide exercises in legato playing.

Beginning in the early twentieth century to 1940, method books began to offer more expansive annotations and provided more detailed explanations of what performers must physically do to accomplish the tasks in each exercise. Again, the materials predominately focus on articulation, scales, range, and slurs. The growing demand of symphonic literature required more brass performers to play melodic passages. This is reflected in method texts that now contain sections on achieving efficient and proper legato. The first method book written for trombone, written by Ernest Clarke, embodies this shift. Clarke gives slightly more detail, describing how students should articulate on a brass instrument. He writes that students should place the forward part of the tongue “gently to the upper gums and let it drop down to its normal position… uttering ‘too’”.62 Clarke also overtly stated that the syllable used to articulate should not be “tut.” E. Clarke is the first to mention that there are multiple ways to articulate. He writes that the tongue is not the principal mechanism in articulation and instead suggests that it is an aid in articulating.

Clarke also believed that performers, with much practice, can start the note without any use of the tongue. Although it is not directly called a “breath attack,” this is a direct reference to that specific technique. The author does not expand upon what sonic

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differences these different articulations elicit. He writes that the “tongue may be used as an aid in articulating the tone” and that “with repeated trials it will be found that the tone does not depend on the tongue; therefore the tongue should not be made too important”.63

For legato technique, Clarke suggests the breath supports the transition of notes and does not cease or interrupt during the transition from one note to the next. Clarke promotes an ideal of legato where one sustains a note without anticipation and moves so quickly to the next note that no transition is perceptible. For a slur, Clarke writes that the tongue should not move after starting the initial note, suggesting that legato movement is not aided by the tongue.64

This is a notable development in pedagogy. Although Clarke’s assertions that the tongue does not move during a slur is later challenged, this exemplifies some of the first texts on performing legato. This method is representative of a continuum of pedagogy that became continuously more detailed on the physiological requirements of performing and more accepting of alternate techniques.

During the first half of the twentieth century, brass pedagogy literature was contradictory regarding articulation details. An updated edition of Arban’s collection for trombone added annotations that clearly advocate the same method of Saint-Jacome’s suggestion of separating notes with the tongue.65 The editor, Alan Raph, writes similarly to Saint-Jacome that returning the tongue to the seal abruptly stops the air and is effective in producing a short note known as a “staccato” in musical phrases. Raph acknowledges

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63 Ibid., 5.
64 Ibid., 6.
65 Jean Baptiste Arban, Arban Method for Trombone and Baritone, ed. by Alan Raph, revised by Charles Randall and Simone Mantia (New York, NY: Carl Fischer Music Publisher, 1936), Introduction.
that one can possibly control the length of the note with the air support but that one more often and more effectively stops the note with the tongue.

In describing the physical techniques necessary for achieving legato, the editors of this Arban method contrary pedagogy to previous sources. They simply advocate that one should practice legato music, softly, with no explanation as to why it would be beneficial. Contrasting the notions by Clarke, Raph writes that legato playing on trombone is achieved by lightly tonguing every note uniformly. They describe this action as a “gentle forward stroke” to the “back of the teeth”, adding that the articulation should never be forceful enough to interrupt the notes, and should only be used as a means of dividing pitches from one to another.66

This is similar to an example given by previously mentioned pedagogical texts that suggests changing the oral cavity to smooth over register changes. When ascending, Arban writes the vowel should change from “ooo” (/u/) to “eee” (/i/) and conversely from “eee” to “ooo” when descending. Although some suggestions, such as changing the embouchure to “pucker towards the center” is rebuked by later tests, this suggestion to change the oral cavity and tongue were widely embraced after 1940. 67

After 1940 there was an eruption of method books specialized for each instrument. Building off the virtuoso era, and method books from the early twentieth century, these method books continued to provide more detailed instructions. In addition, there continued to be a wider acceptance and requirement for fundamental techniques. Texts in the latter half of the twentieth century would often describe multiple techniques,
(e.g. slurring, tonguing, forming embouchures), suggesting that different techniques fit
different individuals and/or performance requirements. These changes reflect the growing
demands of the solo repertoire that requires a wider array of techniques, colors, and
effects from brass instrumentalists. Although there are varying suggestions for
performing specific techniques, it is often approached that there are multiple techniques
to fit individual differences. These methods and texts rarely offer alternate or varied
techniques as a way of consciously altering the sound product and, again, only suggest
alternate methods as a singular means of accomplishing the specific technique at hand.

In addition, the latter half of the twentieth century witnessed the emergence of
brass pedagogy literature that described in great detail the anatomy and physiology of
brass performance techniques without the aid of music examples.68,69,70,71 This literature
was assisted by technological advancements in recording and imaging technology that
allowed researchers to observe what is happening inside the mouth and throat of
performers.72,73 This added more uniformity and depth into the analysis of the
performers’ technique and pedagogy.

The method books of the latter half of the twentieth century often reflected the
demands of performing in an orchestra as well as the demands of winning an orchestral
audition. For example, Schlossberg imbedded music examples that were built from

69 Norman Hunt, *Guide to Teaching Brass*, 2nd ed. (Dubuque, Iowa: WM. C. Brown Company Publishers,
1968), 38.
71 Harvey Phillips and William Winkle, *The Art of Tuba and Euphonium* (Evanston, IL: Summy-Birchard
72 Kenton Frohrip, "A Videofluorographic Analysis Of Certain Physiological Factors Involved In
Performance Of Selected Exercises For Trombone" (Pd. D, University of Minnesota, 1972).
73 John Haynie, *A Videofluorographic Presentation of the Physiological Phenomena Influencing Trumpet
Performance* (Denton, TX: North Texas State University School of Music, 1968), 7.
orchestral audition excerpts, which “emphasizing general ensemble performance practices and basic musicianship (as opposed to the prevailing idiomatic and stylistic cornet performance practices of the era)”. This is significant because the trumpet was primarily used as an ensemble instrument. Schlossberg’s teaching style was mostly verbal, and thus his annotations are brief and concise, as with the method books from Arban, Clarke, and Saint-Jacome. He also advocated that students practice exercises in a variety of styles and articulations; consequently, his exercises are usually left without markings. In general, one can surmise that this shift shows a great emphasis on stylistic diversity, evenness of sound, and flexibility. In fact, the first twenty-two pages focus on flexibility and slurring within the harmonic series. Moving away from extensive chapters on valve dexterity, scales, chromatics, ornaments, and arpeggios found in the virtuosic school, this method teaches performers the necessary skills to achieve a wider variety of styles in the repertoire.

Another quality of methods texts that emerged between 1950 and 1970 is a fixation on the physical and anatomical requirements of playing. Detailed explanations of what one must do to create a proper sound were common. Philip Farkas, author of the first pedagogy literature of this type on horn, writes that he is “thankful for the many generations of horn players who have gradually evolved method out of the old haphazard efforts which must necessarily have been the first players’ approach to horn playing”. The notion of introducing literature that details the physical anatomy greatly contrasts the early virtuosic period of Arban which suggested that annotations were less important.

75 Max Schlossberg, *Daily Drills & Technical Studies for Trumpet* (New York: M. Baron, 1941).
Also contrary to Arban, Farkas adds that etude books are helpful only when one could play the notes. He criticizes past methods that, should the student not be able to perform the exercises, offer no explanation as to how the various difficulties encountered were to be solved.

A contrary school of thought emerged in the later part of the century. With greater attention paid to the various physical components of playing, some pedagogues worried that too much analysis could create paralysis in performing. Arnold Jacobs, whose philosophy is often summarized as “song and wind” focused less on physical components like the embouchure structure and movement of the tongue and more so on the flow of air and the intent of the musical idea.77 His philosophy stated that:

> the embouchure has to be a source of vibration. It cannot vibrate without air -- without a moving column of wind. There’s too much attention paid to the appearance and feel of an embouchure. There should be more attention paid to how you sound and function. If you set rules you will limit the ability to advance.78

Additionally, Jacobs rationalized that every instrument has its own requirements of air flow, and that two people can play the same instrument but must adjust for tuning. The input of air is different for each person because the oral cavity and tongue are different for each person.79 Directly challenging the physical approach of Farkas, Schuller, and others, Jacobs believed that fixating on what physiological change must

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78 Ibid., 23.
occur inside the mouth may work for one individual and not for another, and can lead to inconsistent and unhelpful recommendations.

This philosophy was strongly applied to articulation. Jacobs wrote that the tongue is an “unruly organ and has nothing to do with vibration, but can easily get into the air stream and negatively affect the tone’s production”. To avoid over-compressing air with the tongue, which can lead to valsalva maneuver disorder (i.e. whereby there is a forceful exhalation blocked by a closed airway), Jacobs recommends that performers should not attempt to control the tongue as a muscle and should instead focus on the lips. This notion was adopted by others, such as Claude Gordon, who suggests to strike the note with confidence and simply not “worry about what the tongue is doing”.

In general, after 1940, articulation philosophy widened to accept more varieties. While the notion of separating notes with the tongue (“tut” syllable) was mostly abandoned, some contemporary methods acknowledge its use in playing notes purposefully more abrupt and short in order to match the stylistic idiom of genres like jazz music. However, most pedagogy adhered to Farkas’ text that suggests that the length of the note is determined by the length of time the lip is vibrating. The length of time the lip is vibrating is determined by the amount of time one sustains the note with air support. Thus, the duration and release of the note is not dictated by the tongue closing off the note.

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82 Campos, *Trumpet Technique*, 86.
Most texts introduced thus far suggest that the articulation should occur by placing the tip of the tongue against the back of the teeth or gums and pulling away to release the air like a valve. The notion that the tongue strikes the tone, as introduced by Arban, was refuted on the pretext that the tongue releases the sound by pulling away. Donald Knaub wrote:

before air is released, contract the muscles of the abdominal wall similar to the way they were used to produce the syllable ha or the way they are used to grunt. This contraction compresses the air and provides a solid area of support on which to build a tone. This compressed air is held back with the tongue - the valve that releases air and allows it to pass through the lips and into the mouthpiece.  

Others such as Farkas and Schuller similarly suggest that the tongue does not strike. However, Schuller carefully explains that to avoid creating a “thud” articulation, one should not place the tongue in position of the seal for too long. Schuller avoids teaching the striking of the tone, because he finds that his students frequently bring the tongue forward in preparation too early and create an undesired “daht” articulation. This is an important distinction from describing the tongue as a release valve which would involve a greater accumulation of intra-oral pressure.

Norman Hunt believed that for all types of tonguing, the performer should quickly release the tip of the tongue from the part of the mouth where the gums meet the back of the top row of teeth (except for low notes). Farkas, Philips, and Schuller, and others began to explore the possibilities of changing vowels and articulations for various

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registers, dynamics, and musical effects. Charles Shoults wrote that there “are widely conflicting theories” on the subject of the correct placement of the tongue for brass instrument articulation. Shoults is personally convinced that many fine brass instrumentalists tongue properly but fail to fully understand what they are actually doing. Shoults suggests that softer dynamics should be articulated with a “d” consonant instead of a “t,” and that the vowel of the articulated note should change to reflect the register. For example, low notes, articulated with “toe,” midrange notes with “tah,” and upper register pitches with “tee.”

Bellamah’s survey shows that at this time, although there are slight discrepancies on the various syllables, phonemes for tonguing in the high register usually ended with “e” and “o” or “ah” for low or middle registers. Harvey Phillips writes that for low instruments such as the tuba, tonguing low in the mouth as to touch the lip in between the teeth is acceptable in low ranges. In a popular magazine for music educators, The Instrumentalist, Rex Conner, directly rejects this philosophy writing that the tuba should not tongue through the teeth as the sound quality is “atrocious.”

Phillips recommends “individual experimentation” with different approaches to create a specialized and individualized approach. He advocates that “an infinity of articulations are possible, desirable, and invaluable to musical expression on the brass instruments.” These examples show that articulation pedagogy is not uniform in suggesting that there is one articulation method. That method describes brass articulation

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87 Phillips and Winkle, The Art of Tuba and Euphonium.
as releasing the air by pulling the tongue back after making a seal with the upper gums. While Philips does suggest seeking alternate methods, he does not outline what physical changes could help, or what sonic or acoustic qualities could result from changes. The evolution of brass pedagogy expands on the continuum that welcomes and explores new possibilities that better suits the repertoire and the individual.

Haynie’s study proved that the placement of the tip of the tongue does not change after students attempt to imitate different phonemes.92 The consonant beginning with “t” or “d” is created by the tongue pulling away from the same contact point. What changes between these articulation sounds outlined by Shoults, Hunt, Bellamah, and others, is the vowel following the consonant. These vowels, “o,” “a,” or “e” correspond to the register, changing from low to high, not respectively. The manipulation of the back of the tongue creates these vowel changes. This debunks the suggestions of Rex Conner and others, that suggest using various syllables like “d” at the front of a note to get a softer, more legato entrance, instead of the traditional “t” front.

This verbiage of “tonguing” or “articulating” is confusing and conflicting among brass pedagogues in this generation. Many pedagogues reference the tongue’s function in articulating a note, or creating a vowel shape, without explaining that the tongue provides two functions in its two physiological sections. The tip of the tongue releases the note by pulling away from a contact point-- either the back of the gums, teeth, or between the lips-- which creates the consonance. The back of the tongue manipulates the shape of the oral cavity and controls the vowel sound. This understanding was not clarified until

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Haynie’s study. Even afterwards, it was still not fully adopted and understood by brass pedagogues.

Hunt illustrated silhouette images of the tongue change for the different vowel shapes. Similar to Jacobs, comparing the changing of the oral cavity to mathematician Daniel Bernoulli’s thesis of fluid mechanics model of hydrodynamics. For brass players, the throat (pharynx), tongue, and lips create the smaller opening, shown in figure 2.1, that accelerates the input of air before the air crosses the lips and creates the vibration.

![Figure 2.1. Tongue Position for Syllables “Ah” and “Ee,” respectively](image)

The faster the air speed, the faster the vibration; the faster the vibration, the higher frequency pitch is produced. Thus, it is apparent that the manipulation of the back of the tongue is necessary to change registers. This knowledge significantly effects how a performer can efficiently articulate and smoothly change registers while maintaining a

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full sound. This is paramount in playing legato melodies and in efficiently articulating pitches in various tessituras.

Haynie’s study in 1968 confirmed Jacobs and Hunt’s untested hypotheses. In the past, teachers had two “basic methods of diagnosing student problems – they could listen to a student play and they could watch a student play”. Haynie teamed with radiologist Alexander F. Finaly. Haynie then used a fluoroscope and one of the earliest videotape recorders to document tongue position, teeth and jaw aperture, tongue arching, pivot, mouthpiece pressure, position of tongue for attack, and the position of tongue for double and triple tonguing.

Haynie recorded the performance of numerous well-known performers, including trumpeter Maurice Andre. Many were unaware that the back of the tongue arched to produce changes in register. Although the amount that the tongue arched and the speed in which the tongue moved changed for each individual, it moved in similar manner and direction. He also used this imaging to prove that performers articulate “ta” in a different position than they do when speaking the word “ta,” suggesting that using vocal phoneme analogies are not an effective pedagogy tool for modeling articulation. Haynie claimed that the experiments both changed his own knowledge of performance physiology, asserting that the tongue should remain low in the mouth after recoiling from the initial articulation. Similarly, by displaying non-objective acoustic data, this study will provide pedagogical benefits by visually displaying the sonic effects of various techniques.

96 John Haynie, A Videofluorographic Presentation, 7.
This study will observe the acoustic qualities of all articulation techniques. The literature in the latter half of the twentieth century begins to more consistently acknowledge articulating without the tongue, although usually prescribed as purely a therapeutic exercise. Philips advocates practicing articulating repeatedly with “ho;” this particular phoneme does not require the use of the tongue.97 Similarly, Campos writes that using breath attacks “has therapeutic value since the embouchure and oral cavity must be balanced and in the optimum shape or the breath attack will not speak immediately”.98

Writers who mention the possible technique of starting a note with just the breath warn against using it in performance. Farkas discusses different techniques for beginning notes without the aid of the tongue, but ultimately cautions against using it performance where split-second timing is of paramount importance and the breath attack can be harder to control.99 This thought process is mostly upheld by Jacobs and Campos, who state that one should only use the breath attack when an “imperceptible entrance is desired”.100 Shoults agrees, and further states that he has witnessed many students attempt to start a note by uttering the “ha” syllable, but admonishes its effectiveness by claiming that those students can only hope that the pitch responds at the correct time.101 Again, merely the discussion of these added techniques, although not yet accepted, display the greater exploration of techniques.

98 Frank Campos, *Trumpet Technique*, 86.
99 Farkas, *The Art of Brass Playing*.
100 Frank Campos, *Trumpet Technique*, 85.
Although most texts reject the use of a breath attack in performance, assigning the technique as one for embouchure development, there are a few examples of those who advocate its use in performing. Faulkner writes that a breath attack is “recommended for legato entries, instrumental patterns merging into one another, and in order to introduce rest like interruptions within the course of a soft portato”.102

Trombonist Denis Wick incorporates breath attacks into his pedagogy.103 Wick also comments on some of the articulation pedagogy developments summarized in this section. Wick writes that pedagogues used to teach articulation by suggesting that the tongue starts the note while the brass player utters phonemes such as “too” (/tu/) or “doo” (/du/). Wick warned that “often the tongue-action is frequently over-emphasized and results in an unpleasantly explosive start to loud notes”.104 To remedy this, Wick advocates to practice for days beginning notes with breath attacks to develop articulation techniques that do not hesitate. Like the previously mentioned pedagogues, Wick only suggests using breath attacks as a method or remedy for practicing articulation and not a performance technique. He concludes by reintroducing the tongue saying that the tongue should be “placed during the split second when the inhaled air changes direction” as to not create a weak or explosive entrance.105

104 Ibid., 25-6.
105 Ibid., 26.
Studies on Instrumental Brass Techniques and Acoustical Qualities

As previously mentioned, Haynie’s study was often consulted as a consummate study, but in fact was not the first to use radio imaging. In 1954, Jody Hall at the University of Indiana sought to analyze the non-labial physical and anatomical changes, if any, that occur when trumpet performers make transitions from one register to another, and if these changes have the resulting effect on tone quality. Hall’s findings opposed the pedagogy of the time. He concluded that the following adjustments were prevalent when changing between pitches:

1. A raising and lowering of the jaw.
2. A movement forward or backward of the high point of the tongue.
3. An enlargement of the pharynx.
4. A lowering and moving forward of the hyoid bone.
5. A forward and upward movement of the larynx.

While assessing the acoustical qualities was a purpose of Hall’s study, the findings were mostly qualitative and now considered obsolete given the outdated microphones and spectrographs used. Two more studies, simultaneously conducted in 1967, utilized X-Ray motion picture and cinefluorographic process to ascertain the manipulations of the mouth, throat, and tongue in brass players. Both studies similarly found that the back of the tongue raises to change registers. Joseph Meidts’ study analyzed articulation, finding that the tongue strikes from different places depending on

106 Labial refers to the changes involving the lips. This study was the first of its kind to analyze what changes happen inside the mouth.
the individual and range. However, his study did not ask the subjects to intentionally try tonguing from different locations in order to assess the varying qualities.

Lewis Hiigel used imaging techniques to analyze the movements within the mouth, and their resulting effects on pitch and articulation on brass instruments.\textsuperscript{110} For the subjects in Hiigel’s study, who were all professional, he proposed a null hypotheses that there is no difference in the placement of the tongue when:

1. Playing staccato than when playing legato in like registers.
2. Enunciating syllables than when performing related pitches and styles.
3. Playing staccato in the high register than when playing staccato in the low register.
4. Playing legato in the high register than when playing legato in the low register.

By analyzing the point of contact of tongue, and the extent and direction of the withdrawal from the contact point, Hiigel found significant differences in tongue placement for all four parts of his null hypotheses. He found, in general, the contact point of the tip of the tongue was higher for legato than staccato regardless of register. In all cases, the tongue moved forward and higher for spoken syllables than during performance.\textsuperscript{111} Hiigel added the greatest changes were in posterior of tongue going from middle to high register.

The next year, Fay Hanson sought to analyze the differences in the laryngeal opening throughout different dynamics. Henson found that the laryngeal opening is smaller at low volume levels of performance than higher volume levels. For this reason,

\textsuperscript{110} Lewis Hiigel, "The Relationship of Syllables to Pitch and Tonguing in Brass Instrument Playing" (DMA diss., University of California at Los Angeles, 1967).
\textsuperscript{111} Ibid., 64.
subjects of this study will be asked to play at a middle dynamic to limit the effect of the laryngeal opening on the sound.\\footnote{Fay Hanson, \textit{Brass Playing: Mechanism and Technic} (New York: C. Fischer, 1968)}

John Haynie’s study was often regarded as a more definitive study because it employed many more subjects (300) of elite performance levels. Haynie also utilized technology that did not require a head immobilizer. This would create an unnatural sensation for the subjects. Haynie also used a more scientifically approved method (fluoroscopy) that would be later replicated by others. Kenton Frohrip surmised that there are many pedagogical techniques and philosophies in use regarding tongue position, pharyngeal opening, and teeth and jaw position. Frohrip claimed “surprisingly few of these studies have included the trombone as the performing instrument”\\footnote{Frohrip, \textit{A Videofluorographic Analysis}, 37.}. He used a similar method of fluoroscopy to analyze the manipulation of these organs in performing various trombone exercises. Although this study analyzed a variety of exercises, the experiment did not test various techniques in performing the same exercise. No quantitative analysis was provided for the acoustical components of the various exercises, leaving question as to how efficient were these physical manipulations in achieving the desired sound product. Frohrip’s conclusion opposed the findings of Hall, which then supported the pedagogy, asserting that “no differences appear to exist in the physiological adjustment made in teeth opening and the over – or under bite between subjects, and that the only difference discovered in the physiological adjustments necessary to accomplish certain tasks was in the adjustment of the pharyngeal opening”\\footnote{Ibid., 103.}.
A student of John Haynie, Allan Amstutz, decided to look more in depth at teeth aperture, instrument pivot, and tongue arch for each subject.\textsuperscript{115} Amstutz found that teeth aperture decreased when pitch ascends. The inverse was also true. The angle of the pivot of the mouthpiece to the performers teeth and jaw was found to increase for ascending pitch. Amstutz corroborated that an ascent in pitch was accompanied by an increase in the arch of the tongue. It was observed that the subjects with a minimal change for either teeth aperture or instrument pivot demonstrated a proportionally greater change in at least one of the other areas under consideration, suggesting that all three techniques work together. However, no mention of the acoustical manipulations of these techniques was provided to suggest the efficacy of the various techniques.

As previously mentioned, many of these studies, such as Amstutz’s, were replicated for other specific instruments. Nicholas Campagno observed laryngeal manipulations of flute and clarinet players.\textsuperscript{116} Although Poole’s anatomical findings are inconsequential, Christopher Poole analyzed the physical observations of vibrato in bassoon players.\textsuperscript{117} As discussed in Chapter 1, Poole’s findings exemplify that subjects may be unaware of the internal techniques they are using. Thus, findings of this study are limited to the assumed completion of proposed techniques.

Similar studies were performed with more advanced technology throughout the past few decades. The most recent example, horn performer Sarah Willis collaborates

\textsuperscript{116} Nicholas A. Campagno, Laryngeal Movements Observed during Clarinet and Flute Performance" (PhD diss., University of Texas, 1990).
\textsuperscript{117} Christopher Scott Poole, "Observations of the Larynx During Vibrato Production Among Professional Bassoonists As Indicated in Experiments Utilizing Fiberoptic Laryngoscopy" (PhD diss., University of Arizona, 2004)
with radiologists from the Biomedizinische NMR Forschungs to produce live videos of the movement of the tongue, teeth, and jaw, synchronized with the sound of the horn. The horn was not Willis’ desired instrument and was modified to not obstruct the MRI equipment. Although the video sound is included, there is no analysis of the acoustic components. Additionally, as in Frohrip’s study, the exercises vary, not physical techniques for performing each exercise.\textsuperscript{118}

A paper presented by Bertsch and Hoole displayed the results of using high-speed imaging to analyze the different tongue speeds and manipulations of beginner, amateur, and professional performer. The results found that beginners often tongue with a larger and stronger compression. This study found that in some cases performers articulated with the top of tongue (dorsal articulation). This study was concerned with determining the tongue’s manipulation in performing maximum tempi and did not evaluate the sound quality of the articulations.\textsuperscript{119} Bertsch and Hoole found that performers use different methods for articulating. Specifically, performers utilized slightly different surfaces of the tongue and slightly different locations in the mouth to create the seal.

Studies analyzing brass performance by means of physical manipulations often focus on the physical strain endured by the performer while sounding a brass instrument. Another recent study further analyzes mouthpiece forces. In 1995, scientists devised a measuring system permitting simultaneous recordings of mouthpiece forces and incisor

deflections (Borchers, Gebert and Jung 1995). This study only acknowledges the role of physical components, such as the teeth have on performing, but do not provide quantitative analysis on the acoustic quality.

Acoustical studies using brass instruments do the opposite: provide in depth data on acoustical components without varying the various techniques. Some of the early studies on attack behavior, or transients, was done by David Luce and Melville Clark. These studies established that “attack transients of the non-percussive instruments form an aurally very important temporal segment of the tone in characterizing…timbre”. This suggests that a proper method for comparing vocal and instrumental sounds would begin with comparing aural components of the transient. Luce and Clark recorded the transient times for all instrument families and noted the effects of vibrato, range, dynamic, and note duration on the length of the transient. They found that lower instruments within each instrument family typically have longer transients. Trombone subjects were analyzed sounding a third away from where our subject will play with a transient of .04ms.

Based off the data of this study, it is expected the subject of this study to execute an articulation with a similar transient time. Although this study did not study euphonium, the trombone is very similar in length and it is anticipated that the findings of this study will be in agreement. Kenneth Berger corroborated the importance of the

123 Ibid., 194.
transient in his 1964 study that removed the transient of selected instruments, played these processed samples for listeners, and found that they were greatly hampered in their ability to identify the instrument.\footnote{124}

A 1967 study by Luce analyzes the correlations of brass instrument tones by assessing the qualities of the attack transients and frequency compositions.\footnote{125} This study tested its accuracy of identifying and differentiating instrument timbres by electronically synthesizing tones, judging the synthesis as satisfactory if the synthesized tones cannot be aurally differentiated from the original tones. A later study by S.J. Elliott and J.M. Bowsher intended to accurately measure acoustical components for sound regeneration, combined analysis of acoustic quality with the pressure output of the lungs and mouthpiece.\footnote{126} Varying inputs of pressure were analyzed; but, for pedagogical purposes, that study did not address what mechanisms the performer must manipulate in order to produce different qualities of sounds.

Arthur Benade analyzes the acoustical properties produced by different instrument qualities. Benade discusses the mathematical properties that the metal type, bell flaring, bore size, mouthpiece shape, and instrument curvature have on the acoustical components.\footnote{127} Benade agrees with Helmholtz, that defines the mechanism for generating sound on brass instruments is described as on outward striking reed.\footnote{128}


formulated that theory,\textsuperscript{129} and used imaging techniques to analyze the physical manipulations of the lips\textsuperscript{130} inside the mouthpiece and the acoustical affect.\textsuperscript{131} Their findings mathematically proved what most brass pedagogues agree: adducting the brass aperture changes the pressure and alters the fundamental frequency and the harmonic spectrum.

Other studies analyze the acoustic qualities, but for the purpose of varying instrument properties. In 1970, John Backus and T.C. Hundley sought to find what mechanisms create the diverse harmonic spectrum.\textsuperscript{132} Through these studies one expects to observe harmonic components of brass, unlike vocalists, display formant regions above the fundamental more intense than the fundamental frequency. Backus writes that for brass instruments, this is “largely due to the radiation characteristic of the bell, which is very inefficient at low frequencies”, but “becomes more efficient with increasing frequency”.\textsuperscript{133} Peter Hoekje compared the acoustic qualities – input impedance and radiation patterns – of transients and steady state (sustained) notes in order to determine which instruments feel “open” or “stuffy”.\textsuperscript{134} This experiment analyzed the qualities of transients in duration and harmonic composition but on the variables of different instrument components instead of varying articulation techniques. Knowing what acoustic qualities various techniques elicit may allow pedagogues to pair techniques with

\textsuperscript{129} Neville H. Fletcher, "Excitation mechanisms in woodwind and brass instruments," \textit{Acta Acustica united with Acustica} 43, no. 1 (1979): 63-72.
\textsuperscript{133} Ibid., 509.
specific instrument equipment accordingly. Similarly, Campbell and Greated display harmonic components and formants for trombone and vocal tones, although not directly comparing the two. He discusses the transient qualities of the instruments but not for the voice.\textsuperscript{135}

**Vocal Methods, Technique, and Pedagogy**

One of the earliest vocal method texts still used often is Nicolai Vaccai’s *Metodo Pratico de Canto* (Practical Method of Singing).\textsuperscript{136} This method text appeared in London in 1833 and taught specific techniques such as singing scales, intervals, semitones, syncopation, appoggiatura, gruppetti, trills, and recitative. Techniques are introduced by including emblematic musical examples that isolate the various techniques with short annotations. In the introduction, the editor, John Paton, describes proper Italian diction. This provides the framework of some of the first pedagogy on teaching vocal articulation onset. Although all examples describe how to pronounce vowels and consonances in Italian, this method suggests using the lips and tongue to shape vowels and maintaining that shape in one position during the sustain of the vowel. Paton writes that Italian consonances are softer than English consonances. To produce this softer articulation, the consonances should be formed as far “forward in the mouth as possible; the tongue should actually touch the upper teeth in pronouncing $d$, $n$, $t$, and $l$”. Paton also outlines the method for articulating Italian words such as “paglia”. Executing this articulation

requires the tongue to “touch the roof of the mouth”, drawing comparison to the dorsal articulation for trumpet, outlined by Campos (Paton 1909, v-vi).\footnote{Ibid., v-vi}

Charles Scott provides an ideal description of the sounds elicited by vocal articulation in a two-part volume. Similar to brass pedagogues of the mid-twentieth century, Scott admonishes the term “attack” and prefers articulation, stating that the means for articulation are not as violent as the term suggests. The author writes that there are two kinds of articulation: closed glottis and open glottis. When the glottis is closed, the vocal folds are drawn tightly together, preventing any passage of breath, which builds up an energized beginning to the note. Scott warns that this must be done to produce a “brilliant tone” and not done in excess where each vowel has a “clicking” quality.\footnote{Charles Kennedy Scott, \textit{Word and Tone: An English Method of Vocal Technique for Solo Singers and Choralists} vol. 2 (London: J. M. Dent and Sons Ltd., 1933), 107.} This technique compares to the brass articulation technique where the tongue creates a seal and releases compressed air like a valve. The open glottis articulation should also be practiced and is described as having a “gradualness,” where the note is “brought, on, as it were, imperceptibly, out of nothing.”\footnote{Ibid., 107.} This desired quality bears strong resemblance to the brass technique of a breath attack.

Charles Scott expands upon the difficulties of articulating consonances and vowels in a later text. Scott believed that it is more difficult to sound consonants than vowels. Because more energy must be expended upon consonances, a “sharp, upward thrust of the diaphragm – introduced by, or coupled with, a contraction of the abdomen –
is often required to articulate consonants successfully”.\textsuperscript{140} Contrary to the introduction on Italian consonances, Scott emphasizes that the energy and clarity of consonances are created by compression not relaxation. Similar to brass technique, Scott writes that clarity to the articulation is based upon the pitched vowel that sounds after the consonances; the consonance ‘d’ is soundless without a vowel following the compression. Contrary to brass pedagogy, Scott writes that “consonants come before the note or beat to which they are attached; vowels come upon the note or the beat”.\textsuperscript{141}

While Scott provides descriptions of how an ideal articulation should sound, Richard Miller provides exercises for achieving efficient and healthy onset.\textsuperscript{142} First, Miller writes that singers should practice using an \textit{appoggio} technique. This technique controls the exhale of the breath, allowing for long, supported legato phrases. The gesture of inspiration resists the gesture of expiration, and is renewed by silent inhalations. Miller incorporates this exhalation exercise into articulation, writing:

\begin{quote}
The key to elongating the breath cycle lies in the ability to sing short detached notes while silently replenishing the breath between them so that the muscles and organs of the trunk remain for the extended periods of time quite near the inspiratory position. Breath expulsion is minimal in the short onset, and breath renewal takes place at the moment of termination of the brief phonatory event.”\textsuperscript{143}
\end{quote}

Miller includes examples of detached eighth-note arpeggios with breath marks between each note. Miller writes to breathe efficiently and silently between each note starting with a quarter length. He suggests playing with chordal accompaniment to ensure

\begin{footnotes}
\item[141] Ibid., 279.
\item[143] Ibid., 25.
\end{footnotes}
intonation is being addressed. The final note should be sung remaining in inspiratory posture, where the sternum and rib cage remain in a steady state, and any movement in the abdominal wall should be so small it is barely perceptible.

Miller recommends to gradually increase the number of detached onsets, breathing silently between them, then perform in groupings as in Figure 2.2. The first exercise parts the glottis after each detached note, then quickly re-engages the subsequent note. Later exercises vary the inhalation, thus strengthening the coordination between inhalation, exhalation, and phonation. Miller writes the vocal folds separate and engage “at a rapid rate, either with or without inhalation”. The singer thus develops superb coordination between the muscles of laryngeal abduction and adduction and the muscles of respiration.

Miller advocates that these onset exercises should be an integral part of every vocalists’ daily routine. Regardless of the vowel, a sign that healthy phonation is occurring, is the presence of vibrato on each phoneme, displayed in the “saw-tooth” pattern in the waveform, as in Figure 2.3.

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144 Ibid., 30.
Thus, this study will ask the vocalist subject to sing with vibrato to ensure healthy and efficient onset is taking place.

With technological advances in the 1960s, vocal pedagogues also used video imaging technology to analyze manipulations of the vocal chords, glottis, and pharynx in vowel and tone production. In addition, texts began to show electromyograms of frequency compositions of corresponding vowel formants. William Vennard compares the formants\(^\text{145}\) of vowels with each other. He also draws comparison to the formant of a flute tone playing the same pitch that decays rapidly in higher frequencies compared to the voice. This represents an early comparison of timbre differences between voice and woodwind.\(^\text{146}\)

Miller echoes the same difficulties in producing consonances without disrupting the vowel. This text also analyzes the frequency compositions of recordings of tenor Jussi Bjorling to analyze formant. By analyzing the change of formant regions on a spectrograph, one can determine the vowel being sung without listening to a recording.\(^\text{147}\)

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\(^{145}\) A vocal formant is a concentration of intensity of a particular overtone cluster. These formant regions are what differentiate vowel sounds in the human voice


Although that study will analyze articulations on a single pitch, Miller discusses resonance and vowel exercises, and how they pertain to passing over registers. He displays spectrograms proving, writing that well-trained singers should be able to maintain formant structures throughout all registers. In regard to resonance, vocal pedagogy also depends on diction. For example, Miller writes that a well-trained singer avoids using vowels with bad formant spreading such as /æ/ (In American English this is the “a” in “the bad cat”). Instead, a well-trained singer would then move this vowel to a more resonant neighboring vowel such as /a/ or /ɑ/.

Vowel exercises align with this process and start with a central vowel, then alternate between surrounding vowels, then travel further away from the original vowel. These exercises also begin with consonances. In particular, nasal consonances, such as /n/ or /m/, are particularly helpful as they allow for vowel and consonant elision during the “hum” at the beginning of the phoneme. Figure 2.4 displays this vowel exercise with nasal consonant beginnings.

Figure 2.4. Miller Alternating Vowel Exercise

Miller, 78, fig. 8.9

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148 Miller, *Teaching Tenor Voices*, 78.
Technological advances were also used to mathematically compare the amount of glottal adduction that occurs during three onset types: hard, normal, and breathy. A 1997 study found that strong linear relationships across men and women existed between these various onset types.\(^{149}\) That study determined that hard onsets completely close the glottis with the highest amount of stiffness and the fastest velocity of movement of the organ. Conversely, breathy onsets did elicit a vocal fold adduction of similar shape, but with slower velocity and the adduction did not completely close. This confirms Scott’s assertion. Normal onsets registered velocity in between the two previously mentioned and although the folds did close completely, they remained closed for a shorter duration and closed with less stiffness. A later study analyzed the same manipulations of amateurs singing the same three types of onsets in different registers and intensities.\(^{150}\) Kimberly Steinhauer’s study suggests that certain parameters of voice motor control, such as onset, quality, and fundamental frequency, exist as part of a dynamical system that can be manipulated and learned by amateurs. Various degrees and types of learned hardness and firmness in articulation are described in brass pedagogy, yet no study links the acoustic qualities. That study may suggest performance brass instrumental methods that acoustically and philosophically correspond to vocal methods.

**Physiologic and Acoustic Analysis of Voice Studies**

Standard music textbooks summarize onsets and vowels. Benade includes figures of exact formant regions for each vowels.\(^{151}\) All human and instrumental sounds consist


of a fundamental sound with a system of overtones above the fundamental. A formant is a relative intensity apex of a harmonic. The frequency of the formant, and the distance between these formants, define how humans hear vocal sounds. For example, a human can sing the same fundamental pitch on /a/ or /e/ and the only differences will be these formant regions. These changes in harmonic compositions are similar to timbre changes between instruments.\textsuperscript{152} Similarly, Campbell and Murray superimpose the frequency composition graph over a musical staff to show how the fundamental frequency of the vowel sung is maintained while the formants of the harmonics change to alter the timbre and perceived phoneme of the sung pitch.\textsuperscript{153}

As expected, studies analyze the physiological components required to sing. Many studies refined or expanded upon Janwillern van den Berg’s \textit{Myoelastic-Aerodynamic Theory of Voice Production}, which states that the vocal folds and airflow through them activate sound and are subject to inertia.\textsuperscript{154} Subsequent studies valued this model on vocal impotence, but questioned its ability to describe sustaining vocalization. Herbert Arkebauer found that intraoral pressure is higher for voiceless consonants that voiced consonants when other related variables are held constant.\textsuperscript{155} Nine years later, Yasuo Koike and Minoru Hirano analyzed subglottal air variations along with glottal adduction times.\textsuperscript{156} Koike and Hirano determined that subglottal air pressure is higher when the glottal area shrinks, reaching its maximum pressure reading when the glottis

\textsuperscript{152} Ibid., 64.
\textsuperscript{153} Murray and Greater, \textit{The Musicians’ Guide}, 155.
\textsuperscript{155} Herbert John Arkebauer, “A Study of Intraoral Air Pressures Associated with Production of Selected Consonants” (PhD diss., Univerersity of Iowa, 1964), 64-66.
starts to open. This difference of pressure is a subsequent explanation for one of the
driving forces that drives air through to vocal folds to maintain vibration of the folds.
This is a vocal manifestation of the Bernoulli affect that Hunt outlined for brass
instrument sound production. Ingo Titze also uses this theorem to describe phonation
mechanisms, as seen in figure 2.5.

![Figure 2.5. Bernoulli’s Law of Fluid Dynamics](source)

Figure 2.5. Bernoulli’s Law of Fluid Dynamics
Titze, 71, fig. 3.14

Later models for understanding the mechanics of the voice advance the
Myoelastic-Aerodynamic Theory by explaining the vocal mechanisms that prolong the
vibration of the vocal folds. Studies, such as the ones above, show that pressure differs
below and above the closed (or adducted) glottis, and the elastic recoil of the vocal folds
propel the vibration.\(^\text{157}\) Improvements on the model explore the multiple dimensions
which vocal folds come into contact, often called a three-mass model.\(^\text{158}\) Most recent
models demonstrate the vocal fold vibration with up to eighteen contact points.\(^\text{159}\)
Researchers such as Titze, mathematically prove the influences of multiple mass models,
relying on understandings of spring and recoil laws, as seen in Figure 2.6.\(^\text{160}\)

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\(^{159}\) McCoy, *Your Inside: An Inside View*, 107.

Figure 2.6. A Three-mass model of vocal fold oscillation, including airflow and driving pressure in the glottis. Where “A” is outward movement with a convergent glottis, and “B” is inward movement with a divergent glottis. Note the direction of the net velocity of the tissue in relation to pressure “P.”

Titze, 95, fig. 4.8

These observations were further clarified with technological advancements of high speed imaging\(^{161}\) and Magnetic Resolution Imaging.\(^{162}\) These studies demonstrated that specific glottal opening shapes correspond to specific vowels. However, most of the vocal mechanisms used for transforming the formants are controlled by the shape of the


vocal tract or resonators. Similarly, the vocal mechanisms used to manipulate the sound quality of the consonant are controlled by articulators such as the teeth and tongue.

Additionally, later studies analyzed the multiple pressure differences occurring in stops- in subglottal area, and “from atmosphere by constrictions formed by the soft palate and posterior pharyngeal wall, and/or by the lips or tongue and palate”. The study found that for unvoiced consonances (\(p/,t/,k/\)) were comprised of a silent glottal closure, and accompanied by decreases in supraglottal volume. Conversely, voiced consonances (\(b,d,g\)) displayed significant intervals of vocal fold vibration during closure, and relatively large increases in supraglottal volume. These volume changes are created by enlarging the supraglottal cavity, pushing air against an occluded glottis, stopped by articulators (pharynx, tongue, lips) creating vibrations prior to the phonation. Because of this anatomical understanding, this study will expect to observe these shapes in the envelope of the transient. This is corroborated by a 2004 study that sought to compare the Voice Onset Times (VOT) of trained and untrained male vocalists. The study found that VOT was longer for trained male vocalists, indicating that the VOT is longer because of increased articulatory control. Additionally, this study found that “differences in voiced and voiceless stop VOT were observed, with voiced stops having shorter VOTs than voiceless stops, and labial stops having shorter VOTs than alveolar

\[\text{References:}\]

164 Voiceless consonances are consonances where the larynx is not vibrating during the consonant.
165 Voiced consonances are consonances where the larynx is vibrating during the consonant.
and velar stops”. These measurements only measure time, and not the shape of the envelope change or comparative strength of the transient.

A later study acknowledged these pressure differences and analyzed the Vocal Attack Time (VAT), defined as the time lag between the growth of sound pressure (amplitude) and electroglottographic signals at initiation. This study divided voice onset into abrupt or hard, normal or simultaneous, and breathy, aspirate, or soft glottal attacks. This study observed aspirate onset types in speech and found a significantly longer VAT for aspirate versus unaspirated onsets. This study will expect to observe longer, gradual onsets in phonemes such as “Hah” versus “Ah”.

Other studies have analyzed the relationship of the fundamental frequency and the onset of voice. A study by Ralph Ohde examined the Fundamental Frequency ($F_0$) of utterances containing unvoiced aspirated (e.g. /p/,/t/,/k/), unvoiced unaspirated (e.g. /sp/,/st/,/sk/), and voiced stop (e.g. /b/,/d/,/g/) consonants. The study found that unvoiced aspirated and unvoiced unaspirated consonants had almost identical $F_0$ and voiceless consonants had higher $F_0$ values voiced consonants. That study did not support a simple rise-fall dichotomy of $F_0$ that had been previously proposed. A later study observed whether or not the larynx, and changes in the pressure above and below the glottal closure, are something that is able to be controlled by vocalists. While observing

167 Ibid., 422.
that “transient changes in F₀ can be quite large”, the researchers found that the “larynx is no better compensated for the perturbing influence of relatively rapid changes in transglottal pressure during highly trained singing than it is during ordinary speech”.¹⁷² Because these F₀ changes are so dependent on phoneme type and individual, this study will not choose to use fundamental frequency modulations as a method of comparison.

CHAPTER 3: METHODS

The purpose of this study is to quantitatively and qualitatively correlate the acoustic manipulations of various euphonium articulation techniques with the acoustic qualities of articulating various phonemes with the human voice. In order to accomplish this, first a compiled list of techniques for performing articulation was collected by observing preeminent brass method, pedagogy, and relevant texts. These lists of techniques will be provided to a member of the University of Miami Frost School of Music Euphonium Studio. The recorded acoustical data will be used to assess these research questions:

1. What techniques for brass performance were advocated in method, pedagogical, and relevant texts for performing articulation?

2. Discussion of accepted articulation techniques present in method, pedagogical, and magazine texts.

After compiling these techniques, this study will assess:

3. What are the transient qualities of various brass articulations and vocal articulations (onsets)?
   i. What qualitative comparisons can be made between the attack envelope of various instrumental brass techniques and vocal phonemes?
   ii. Can a quantitative measure be used to describe, define, and/or correlate brass articulation techniques and vocal phonemes?
   iii. Are there any defining characteristics of the harmonic composition of the attack transient that describe, define, and/or correlate brass and vocal articulation?
All recordings for this study will take place in a “dead room”, or a room with a high decay rate. This dead room will eliminate room noise and allow accurate and consistent analysis of transients, harmonic composition, amplitude, and timbre variations. Recordings will be gathered with a single Earthworks M50 Reference Microphone connected to a Merging-Morus PreAmp at a 48kHz sample rate. Inside the isolation booth, the microphone will be placed on an equal plane one meter from the bell.

Similarly, the vocalist will sing directly into the same microphone one meter from the opening of his mouth. The proximity will provide consistent analysis of harmonic content and amplitude of entrances.

**Vocal Articulation/Onset**

The vocalist subject will be accepted as a lyric tenor with advanced degrees in vocal training. As mentioned in Chapter 2, onset times are influenced by the amount of vocal training. A lyric tenor will be selected because the repertoire written for lyric tenors is often performed by euphoniumists. Miller writes that a lyric tenor is the “ideal” tenor for much of the operatic literature, as well as Handel oratorios, German Lied, and French mélodie. Miller writes that a lyric tenor is the “ideal” tenor for much of the operatic literature, as well as Handel oratorios, German Lied, and French mélodie. Passaggi points typically occur at D4 and G4. An individual with an advanced level of musical training will be able to demonstrate articulations representative of a high standard. Additionally, a lyric tenor has the closest

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175 Passaggi are perceptible registration zones in the vocal register where, particularly for untrained singers, changes in timbre are perceptible. Such changes come about because the laryngeal muscles do not remain in a static posture throughout the mounting scale.
timbral similarities to the euphonium which will facilitate comparisons of phonemes with different formant regions.

A vocalist will sing an A3, at a comfortable *mezzo-forte* dynamic, with vibrato, for exactly two seconds. A click track, or metronome provided over headphones, at 60 bpm with a drone sounding an “A” at 440HZ will play through an earpiece. This will provide the vocalist the precise pitch and duration, ensuring the recordings are uniform.

**Selection of Phonemes**

A phoneme is defined as a one of the smallest units of speech that distinguish one utterance from another.\(^{176}\) A complete pairing of all phonemes that can be created from all the languages in the world is too large for this study to account for.\(^{177}\) For this study, a selection of phonemes that is both representative of different categories of articulation and relevant to brass articulation will be necessary.

Articulations or phonemes are divided into two categories: sonorant and obstruent.\(^{178}\) A sonorant is a speech sound that is produced with continuous, non-turbulent airflow in the vocal tract. Vowels are sonorants, as are nasal consonants such as /m/ and approximates such as /l/. Obstruents are consonants that are formed by obstructing airflow, such as /d/ or /k/.

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\(^{178}\) Ibid., 24.
Dorothy Uris writes that singers begin their routine practicing legato on vowels.\textsuperscript{179} Similarly, this study will begin by selecting and analyzing vowels. Although there are only five vowel letters in the English language, there are sixteen vowels sounds in spoken American English language. The parameters that define most vowels systems “are the three scales whose endpoints are traditionally called high and low, front and back, and rounded and unrounded”.\textsuperscript{180}

Figure 3.1. Primary Cardinal Vowels Displayed in Terms of the Major Dimensions of Vowel Quality
Ladefoged, 283, fig. 9.1

The height refers to the amount that the tongue ascends towards the hard pallet. A vowel that is located in the front is defined by the tongue being positioned as far in the front as possible without creating a constriction that would make it a consonant. A back vowel moves in the opposite direction. Rounded and unrounded refer to lip position. When a rounded vowel is pronounced, the lips form a circular opening; unrounded vowels are pronounced with the lips relaxed.\textsuperscript{181}

\textsuperscript{180} Ladefoged and Maddieson, \textit{The Sounds of the World’s Languages}, 282.
\textsuperscript{181} Ibid., 98.
It is often agreed upon that the style many brass players attempt to most emulate from vocalists is legato. Uris writes that singers practice legato on the vowels /ɑ/ or /u/. This study will select these two vowels. The phoneme /ɑ/, or cardinal vowel number five, has a low and back tongue position and is unrounded. The phoneme /u/, or cardinal vowel number 8, has a high and back tongue position with rounded lips. Figured, 3.2 and 3.3 show the lip positions for /ɑ/ and /u/, respectively.

A lateral sound is “defined as those sounds which are produced with an occlusion somewhere along the mid-saggital line of the vocal tract but with airflow around one or both sides of the occlusion”. The most common types of laterals, voiced lateral approximants, are rhotics (r-sounds) such as “row” /roʊ/. Thus, this study will select the lateral /r/. All following consonant types will be combined with /ɑ/. Previous spectrograms of laterals have shown that the first and second formants of the /r/ is lower. When, a lateral is adjacent to a vowel, as it will be in this study, the formant change is observable.

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182 Uris, To Sing in English; a Guide to Improved Diction, 79.
184 Ibid., 72.
185 Ladefoged and Maddieson, The Sounds of the World’s Languages, 182.
186 Ibid., 193.
A nasal consonant is the last category of sonorants. A nasal consonant is “one in which the velum is lowered and there is a closure in the oral cavity somewhere in front of the velic opening. Hence, air from the lungs is directed out through the nasal passage alone”.\textsuperscript{187} This study will observe nasal consonances by involving the phoneme /n/\textsuperscript{a/}. Spectrograms show that formants are less defined during nasal consonances than during the vowel.\textsuperscript{188}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3_4}
\caption{Aerodynamic Records of Nasal Consonants}
\end{figure}

\begin{flushright}
Ladefoged, 105, fig. 4.2
\end{flushright}

\begin{footnotesize}
\textsuperscript{187} Ibid., 102.
\textsuperscript{188} Ibid., 102.
\end{footnotesize}
The above figure shows physical and audio effects of a nasal consonant /m/. When an obstruent in the mouth directs airflow through the nose, the envelope is weakened. This figure shows that oral airflow is interrupted and nasal airflow is activated during the nasal consonant.

The obstruent category, also known as “stops” or “oral occlusive”, occur in every language known on earth. Stops may be distinguished from one another by “place of articulation, variations in the glottal state, airstream mechanism, and the articulatory activity during onset and offset”.¹⁸⁹ However, in American-English only places of articulation and variations in the glottal state are relevant parameters, as the airstream mechanism is always a plosive and extra articulatory activities during onset or offset don’t exist in English. In generalized English, the larynx may or may not be actively vibrating during the consonant. If the larynx is vibrating during the consonant, the resulting phoneme is referred to as voiced (an example is the “d” in “door” /dɔr/); if the larynx is not vibrating during the consonant, the resulting phoneme is called voiceless (an example is “t” in “table” /ˈteɪbəl/). Figure 3.5 demonstrates that laryngeal vibration, although decreased, are still active during both voiced consonances /d/ and /b/ in the word “buddha”.

¹⁸⁹ Ibid., 47.
Just as with brass articulation, there are many different articulation surfaces.

Figure 3.7 displays the five groups of moveable structures forming the active articulators in the vocal tract.
These moveable parts contact nine target areas when articulating, as displayed in Figure 3.8.

This study selected syllables which related to brass articulation. These involve the tip of the tongue as the articulator as it made labial and alveolar contact. Additionally, as with the dorsal articulation in brass instruments, this study observed the back of the tongue contacting the velar region. These contact points, labial, alveolar/dental, and velar can either be voiced or unvoiced. This study selected each of these combinations. Table 3.1 provides examples of combinations of places of articulation, articulatory target region, moving articulator, and the resulting phoneme symbols. Table 3.2 displays phonemes and their defining characteristics selected for this study.
Table 3.1. Terminology Summarizing the Place of Articulatory Gestures

Ladefoged, 15, table 2.1

A derivation of a stop or plosive is an affricate consonant. In most cases, there is a brief period where the tongue is released from its contact point which causes a constriction that is narrow enough causing turbulence in the airflow. Affricates are “stops in which the release of the constriction is modified in such a way as to produce a more prolonged period of frication after the release”. An example of an affricate, and the phoneme used in this study is the “ch” in “cheer” /ʧɪr/.

A fricative sound is one in which a turbulent airstream is produced within the vocal tract. The most common is a sibilant. The sibilant’s principal source of sound is the turbulent airstream produced when the jet of air created by the dental or alveolar constriction strikes the teeth, which form an obstacle downstream form the constriction itself. An example of this, and the phoneme used in this study, is the consonant “s” in the word “sap” /sæp/. The defining turbulent airstream created during the oral obstruction

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190 Ibid., 90.
191 Ibid., 145.
creates a transient that emits high frequency. Figure 3.9 displays the frequency composition of /s/, showing a resulting concentration of high frequencies around 4,000 HZ. This study will expect to observe similar characteristics when analyzing the harmonic content.

![Spectrogram of Sibilant /sa/](image)

**Figure 3.9: Spectrogram of Sibilant /sa/**

Ladefoged, 162, fig. 5.19

Other phoneme categories were excluded because they did not relate to brass articulations and would not draw a comparison. Similarly, a flap or tap is a type of consonant sound, which is produced with a single contraction of the muscles so that one articulator (such as the tongue) is thrown against another. An example of a tap is the “tt”/ɾ/ in “latter” /læɾə/. This gesture only occurs in the middle of a multi-syllable phoneme and is not relevant to an onset articulation. Lastly, from the vowel category, diphthongs were excluded because they do not relate to brass articulations. If vowels have one target region, a diphthong has two different elided targets. Other, multiple articulatory consonances were also excluded. These syllable types would not relate to

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192 Ibid., 321.
brass performers because they do not try to move or change characteristics in the mouth while sustaining a single pitch.

<table>
<thead>
<tr>
<th>Speech Sound Type</th>
<th>Phoneme Category</th>
<th>Specific Type</th>
<th>IPA</th>
<th>English Word Example</th>
<th>Articulation Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonorant</td>
<td>Vowel</td>
<td>High Back Rounded</td>
<td>/u/</td>
<td>Boot</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low Back Unrounded</td>
<td>/a/</td>
<td>Cot</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Semivowel (rhotic)</td>
<td>/ɾ/</td>
<td>Row</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nasal Consonant</td>
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<td>/n/</td>
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<td>Obstruent</td>
<td>Plosive</td>
<td>Unvoiced</td>
<td>/p/</td>
<td>Pat</td>
<td>Labial</td>
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<td></td>
<td></td>
<td>/t/</td>
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<td>Tap</td>
<td>Alveolar</td>
</tr>
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<td>/k/</td>
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<td>Kill</td>
<td>Velar</td>
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<td></td>
<td>Voiced</td>
<td>/b/</td>
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<td>Bat</td>
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<td></td>
<td></td>
<td>/d/</td>
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<td>Dog</td>
<td>Alveolar</td>
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<td>/g/</td>
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<td>Good</td>
<td>Velar</td>
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<td>Cheer</td>
<td>Palate-Alveolar</td>
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<tr>
<td>Fricative</td>
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<td>/s/</td>
<td></td>
<td>So</td>
<td>Dental</td>
</tr>
</tbody>
</table>

Table 3.2: List of Phonemes Analyzed

**Euphonium Articulation**

The euphonium player subject will play with the same earpiece ensuring the same pitch and duration is ingrained. The euphonium player will be asked to articulate each technique to the best of his or her ability three times. If one trial was a mistake, or not demonstrative of ability, the subject will be asked to alert the recording engineer. The trial will be removed. The instrumentalist will be instructed to perform these articulation techniques, verbatim:

First a control will be required. Articulate on “A” as one would normally do, using the music training one has received thus far.
1. Articulate using the tongue, placed at the back of the teeth, to release compressed air “like a valve.” Compress the air behind the tongue and release the tongue quickly. This articulation method should feel similar to the act of “spitting.”

2. Articulate using the tongue to strike and quickly release, simultaneously releasing a column of air. Please perform an articulation where the tongue strikes and releases from the following locations:
   a. The gums on the roof of the mouth
   b. The back of the upper teeth
   c. The inside of the upper lip of the upper embouchure, below the upper teeth.

3. Form the structure of the embouchure and release a column of air, or “breath attack,” the note with the valve already compressed.

4. Form the structure of the embouchure and release a column of air, or “breath attack,” the note while simultaneously compressing the valve.

5. Dorsal or anchor articulation. Described by Herbert L. Clarke, the technique “involves keeping the tip of the tongue ‘anchored’ behind the bottom teeth and tonguing with the middle or dorsal aspect of the tongue”. This articulation should be similar to the second consonant used in a double tongue technique. Additionally, it will feel as if you are saying /ka/.

The recordings of the vocalist and all recordings of the euphonium player will each be normalized. All recordings will be collected and displayed between the values of negative one and one. Analyzing the envelope shows only the positive values of the sound and

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193 Campos, *Trumpet Technique*, 84.
displays the signal strength or amplitude. Normalizing all recordings against themselves will adjust the loudest moment to the value of one and keep all others in proportion. If individual trials are inconsistent or if certain techniques yield louder articulations than others, this normalization technique will facilitate comparisons. Inherently, euphonium and voice will be different amplitudes, and thus they will not be normalized with each other.

**Methods for Analyzing Transients**

The method for comparing articulation qualities is most effectively done by generally comparing the shape of the envelope. A 1964 study found that a group of auditors were able to identify the instrument producing a tone by listening to only the attack transient tone, proving that a paramount characteristic of identifying timbre is the attack transient. However, there are studies that question the difference between analyzing the transient based on what humans can perceive aurally and what is apparent. Joos Vos and Rudolf Rasch describe this dichotomy:

> The perceptual onset of an acoustic stimulus, such as a musical tone or a speech syllable, can be defined as the moment in time at which the stimulus is first perceived. The physical onset, however, can be defined as the moment at which the generation of the onset has started.

This study will primarily focus on the measurements of the physical onset; however, considerations will be made to factor on the perceptual differences of these

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194 Melville Clark et al., “A Preliminary Experiment on the Perceptual Basis for Musical Instrument Families”, *Journal of the Audio Engineering Society* 12, no. 3 (July 1, 1964): 199-203.
measurements. The first measurement of this study will analyze how precipitously the amplitude increases to the apex. Whether the note shapes have a flaring conical shape, exponential upstroke, or block-like start will correspond to the strength and efficiency of the articulation. Additionally, this analysis technique will observe if notes start with a “pop”. If the apex of the amplitude is greater than the amplitude of the steady-state or sustain, there is an apparent forceful jarring articulation.

After normalizing each recording, a slope, derived as a function of increase or change in amplitude (Decibel or dB) from nothing to the steady state of the sound envelope over time (MS), can be measured for each trial. This numerical value, represented as “m”, can be averaged over the three trials and used as a representative quantitative comparison for each articulation technique. The study by Joos Vos and Rudolf Rasch numerically compares the slope gradient and shows there is a precedence for using this method.\textsuperscript{196} This method will complement comparisons of qualitatively comparing the shape of the envelope. It is anticipated that articulations will not increase uniformly and remain at steady state. Instead, many may irregularly reach the apex of amplitude and descend to a steady state. For this reason, this study will not attempt to trace the exponential growth and decay of the envelope using exponential or sinusoidal functions, as was done by Koster et. al.\textsuperscript{197}

\textsuperscript{196} Ibid., 4.
Method for Analyzing Harmonic Content of Transient

Previous studies have analyzed attack transients by observing the amplitude and by using Fast Fourier Transformations (FFT) of the transient to observe which specific harmonics grow to higher intensities in short durations. The mathematician Fourier created an algorithm that proved that “any continuous function could be produced as an infinite sum of sine and cosine waves”. His results are often used in analyzing harmonic or overtone content and for Magnetic Resolution Imaging. The sounds of orchestral instruments “usually consists of a fundamental and a complement of harmonics, which can be considered to be a superposition of sine waves of a fundamental frequency and integer multiples of that frequency”.

Because they have a different timbre, the harmonic composition of a voice and a brass instrument will be different, even if they are eliciting the same fundamental frequency. Harvey Fletcher wrote about this in an early study, stating that “timbre depends principally upon the overtone structure; but large changes in the intensity and the frequency also produce changes in the timbre”. This does not mean that comparisons of harmonic composition are useless. General similarities of certain harmonics in different ranges appear early or late, at different intensities, and can be observed. For example, although the harmonic content will be inherently different, certain articulation

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techniques may yield a high intensity of high frequencies in the initial sound envelope.

This could correspond to a vocal onset phoneme that also has a bright attack.
CHAPTER 4: DISCUSSION OF DATA

In this chapter, findings relative to the research questions are discussed. Different articulation techniques for euphonium and voice were grouped into categories based on the similarities of the recorded data. The findings for euphonium and voice are discussed separately.

Table 4.1 displays the quantitative findings and calculations. The technique number, and applicable subsequent letter, refers to the technique described to the subject in Chapter 3. The last digit in the “Technique” column (1, 2, or 3) refers to the trial number offered by the subject.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Articulation Time (dsec)</th>
<th>Average Articulation Time</th>
<th>Articulation Time Range</th>
<th>Articulation Slope (amp/dsec)</th>
<th>Articulation Slope Average</th>
<th>Articulation Slope Range</th>
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<td>0.800</td>
<td>0.48</td>
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<tr>
<td>Control 3</td>
<td>1.7</td>
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<td></td>
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<td>1.2</td>
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<td>0.9</td>
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</tbody>
</table>

Table 4.1. Quantitative Data of Each Accepted Technique and Trial
Qualitative Analysis of Euphonium and Vocal Articulation

A qualitative comparison of the envelope found results consistent with expectations. For all figures, the sound strength is represented by the blue waveform. A red, Attack Decay Sustain Release (ADSR) line traces the curve of the envelope. In general, most articulations utilizing the tip of the tongue to make contact and release (Technique 2a.1-2c.3) and the control (Control 1-3) display a sharp rise in the envelope, followed by, at most, a minimal decay. This similar attack and sustain shape is seen clearly in Figures 4.1 and 4.2.

![Figure 4.1. Waveform and ADSR of Control 2](image1)

Figure 4.1. Waveform and ADSR of Control 2

![Figure 4.2. Waveform and ADSR for Technique 2a.2](image2)

Figure 4.2. Waveform and ADSR for Technique 2a.2

Articulation Technique 1 also uses the tip of the tongue to make an occlusion and release. This technique, as well as velar or dorsal articulation (Technique 5) offers different characteristics. As seen in waveform readings in Figures 4.3 and 4.4, the attack increases more precipitously, falls away, and recovers into the sustain. Technique 1 asks the instrumentalist to build up intraoral pressure by creating a seal and releasing it
quickly. Similarly, a velar or dorsal articulation builds a higher intraoral pressure when creating a seal with the blade of the tongue, against the roof of the mouth, or velar region. It is logical to reason that this release of high pressure air is not immediately sustained in the exhalation, and thus there is a decay after the initial peak, creating this uneven attack.

Figure 4.3. Waveform and ADSR for Technique 1.3

Figure 4.4. Waveform and ADSR for Technique 5.1

Surprisingly, transient shapes and strengths of techniques utilizing breath attacks (Techniques 3 and 4) were similar to techniques using tongue. Literature that summarized breath attacks as erratic and slow to respond was not supported by the analysis of waveform and ADSR lines in this study. Figure 4.5 displays a gradually increasing, irregular, articulation that one who was informed by previous decades of pedagogy would expect to see in a breath attack. However, Figure 4.5 displays Technique 2c, where the
instrumentalist makes contact with the tip of the tongue on the inside of the lip below the teeth. Conversely, Figure 4.6 shows a precipitous and regular transient of a breath attack.

Vocal articulation methods are much more varied, and thus, the articulation waveforms were understandably more varied. In general, vowels and voiced consonances also contained precipitous and even growth during the transient. All voiced consonances contained comparable structures. Figure 4.7 displays the waveform for the vowel /u/, as well as voiced consonances /b/ and /d/. The waveform shows the “saw-tooth” pattern indicating healthy onset and vibrato, and a precipitous and regular transient growth also found in voiced consonances. During a voiced consonant, the larynx is activated. This explains the comparatively strong transient growth.
Voiceless, nasal, affricate, and fricative consonances display similar characteristics, but are markedly different from the vowel group previously mentioned. While the consonance is being formed, the waveform exhibits minimal growth, followed by strong growth when the vowel is formed. This phenomena is displayed in Figure 4.9. In the following sections, spectral analysis of the transient and mathematical analysis of attack time and attack slope will further assist analysis.
Quantitative Analysis and Measures of Attack Transients

In general, Euphonium Attack Time (EAT) was faster and more precipitous in growth than Vocal Attack Time (VAT) and growth. The average attack time for all euphonium techniques and trials was 1.85 deciseconds (ds). VAT was 67% greater at 3.03 deciseconds. Additionally, the slope function was greater for euphonium articulations. The average euphonium slope showed articulations grew .55 Amplitude per
decisecond; whereas, vocal articulation registered 52% more gradual at .27 amplitude per decisecond. It is also of note, as evident in Table 4.2, that euphonium articulations were more uniform.

| Euphonium Attack Time Standard Deviation | 1.190542441 |
| Euphonium Slope Standard Deviation | 0.63557356 |
| Vocal Attack Time Standard Deviation | 1.552027023 |
| Vocal Slope Standard Deviation | 0.149929276 |

Table 4.2. Standard Deviation of Attack Measurements for Euphonium and Voice

Specifically VAT was more varied by 30%; however, it is significant to note that euphonium slope measurements were more varied by 342%! The greater VAT, and greater variance of VAT, is again explained by the varying mechanics of pronouncing varied phonemes.

For euphonium specifically, the qualitative measurements are supported with what was observed by analyzing the waveform. Techniques 1 and 5, which exhibited the explosive growth in the waveform observations due to built up intraoral pressure, registered fast attack times and precipitous growth slopes. Specifically, averaged among the three trials, EAT and slope were .87ds and .83Amp/ds for Technique 1 and 1ds and .87Amp/ds for Technique 5, respectively.

Additionally, the similar waveforms observed for Techniques 2-4 were supported by these qualitative measures. Average EAT for all of Technique 2a-c was 144% longer than the average attack time of Techniques 1 and 5 at 2.28ds versus .93ds. Similarly, the slope was 184% larger for Techniques 1 and 5 than the average for Technique 2.
Qualitative measures yielded additional considerations. Average EAT and slope measures for breath attack techniques (3 and 4) and Technique 2, which sought to coordinate the exhale with the release of the tongue, decreasing intraoral pressure, were similar. Specifically average EAT only differed 1 millisecond (ms) and the slope average only differed .0083Amp/dsec. This could suggest that techniques for simultaneously coordinating exhale, and the release of the tongue and breath attacks, yielded similar results.

However, analysis of the specific technique trials confronts this suggestion. For example, Technique 2 exhibited minimal differences in EAT and slope averages among the tongue placements (displayed as A-C). As seen in Table 4.1, there are greater ranges of data, in particular between techniques 2B and 2C, suggesting an irregularity of the technique. This contradicts the similarities of the average readings.

Qualitative measures of the two breath attack techniques (Techniques 3 and 4) were unexpectedly different. Although both techniques did not restrict an exhale and thus did not considerably build intraoral pressure, there were markedly different attack times and resulting slopes. Confronting notions that breath attacks were hard to control and gradual, EAT for this technique were all within 1ds range and showed a fast attack, averaging 1.3ds. Technique 4, which simultaneously compressed the valve while performing the same breath attack displayed very different results. While this technique hoped to strengthen the regularity of the technique by coordinating an external physical stimuli in the hand (compressing the valve) with an internal impetus (exhaling the breath attack), the qualitative measures suggest the opposite. The average EAT of Technique 4 was gathered over a comparably wide range of 2.9ds. The outlier in the subset, trail 4.1,
was a similar time, 1.4ds. The true result showed that this technique slowed the growth of the transient. As seen in figure 4.10, there is a characteristic “hitch” in the growth of the attack, similar to the one discussed in Technique 1 and 5, but of a smaller degree. This reasonably suggests the effect of the compressing valve, changing the length of the instrument by adding more tubing, thus altering the resistance of airflow, and ultimately delaying the growth of the transient.

![Waveform Envelope of Technique 4](image)

Figure 4.9. Waveform and ADSR for Technique 4.3

Additional considerations need to be made for other subsets with wide ranges of data. The largest range of EAT, and subsequent largest range of slope measures, was recorded for Technique 2b. As seen in Figure 4.10, the algorithm that traces the ADSR plots the peak of the attack after another possible peak.

It is possible that the euphonium subject increased volume after the articulation, explaining the resulting shape of the waveform. This would have incorrectly plotted the attack peak at 4.3ds, almost half a second! More realistically, the transient ends approximately 1ds after initiating, as with the other trials.
Figure 4.10. Waveform and ADSR for Each Trial of Technique 2B. The first trial begins at the top, continuing down until the third trial.

If this trial was expunged, the average EAT would be 1.2ds, and the slope would be .48Amp/ds. This data would suggest that this technique has the fast attack time, characteristic of Techniques 1 and 5, with the less precipitous growth characteristic of the breath attack Technique 3.

Quantitative measurements of transients for vocal phonemes also mostly supported observations of waveforms. For a full list of measurements, refer to Table 4.3.
<table>
<thead>
<tr>
<th>Phoneme IPA</th>
<th>Phoneme Shorthand</th>
<th>Articulation Time (dsec)</th>
<th>Articulation Slope (amp/dsec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/a/</td>
<td>aaa</td>
<td>4</td>
<td>0.17</td>
</tr>
<tr>
<td>/u/</td>
<td>uuu</td>
<td>1.4</td>
<td>0.14</td>
</tr>
<tr>
<td>/r/</td>
<td>raa</td>
<td>3.2</td>
<td>0.18</td>
</tr>
<tr>
<td>/d/</td>
<td>daa</td>
<td>1.1</td>
<td>0.49</td>
</tr>
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<td>taa</td>
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<td>0.41</td>
</tr>
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<td>/p/</td>
<td>paa</td>
<td>1.9</td>
<td>0.35</td>
</tr>
<tr>
<td>/b/</td>
<td>baa</td>
<td>1.2</td>
<td>0.57</td>
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<td>/g/</td>
<td>gaa</td>
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<td>0.24</td>
</tr>
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<td>/k/</td>
<td>kaa</td>
<td>5</td>
<td>0.14</td>
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<tr>
<td>/n/</td>
<td>naa</td>
<td>4.3</td>
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</tr>
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<td>/s/</td>
<td>saa</td>
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<td>0.17</td>
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<tr>
<td>/ʧ/</td>
<td>chaa</td>
<td>4.5</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Table 4.3. List of Measurements of VAT and Slope Measurements

Voiced phonemes measured a shorter VAT, averaging 1.67ds. The subset of phonemes observed in the first section with the irregular growth pattern, voiceless, nasal, affricate, and fricative consonances, registered 66% longer VAT, averaging 3.9ds. The voiced group also exhibited a comparatively larger slope, .43Amp/ds. The second subset was 36% less precipitous at .24Amp/ds. There was less variation of VAT for the voiced consonances, displaying a data range of 1.6ds, compared to the subset discussed with a data range of 3.6ds. Conversely, the slope ranges were slightly more varied for the voiced group of consonances (.33Amp/ds) compared to the subset discussed, .27Amp/ds. This is understandable as the second technique contains more phonemes that require different tongue movements, such as the affricate. However, for all of these phonemes in the second subset, the same general shape was upheld. As the consonant was formed, there was muffled growth followed by precipitous growth as the consonant transformed into the vowel.
Although the VAT of the two vowels, /ɑ/ and /u/, are very different, 4ds and 1.4ds, respectively, the slope measure is very similar: .17Amp/ds and .14Amp/ds, respectively. A possible explanation is that these two vowels peak at different levels, but grow at the same rate, retaining their defining similarity of gradual growth. The semivowel rhotic used, /r/, appears to blend the characteristics of the consonant and vowel. In Figure 4.11, one can observe the characteristic “hitch” in the growth, characteristic of voiceless, nasal, affricate, and fricate consonances, but to a lesser degree.

The VAT of the semivowel fits within the range of the VAT for the vowel phonemes. Additionally the slope measurement for the semivowel, .14, relates closely to the vowel measurements of .17 and .14Amp/ds. This again suggests that the semivowel mimics the growth of the vowel while displaying some characteristic of a consonant.

**Harmonic Analysis of Attack Transients**

Analysis of harmonic content corroborates the groupings of articulation types made in the first two sections. Again, there are similarities between Techniques 1 and 5, 3 and 4, and all types of Technique 2. The figures in this section display a spectrogram, or a spectrum reading of the intensity of a frequency (represented on the “y” axis) over time in seconds (represented on the “x” axis). The segments are extracted from the waveform recordings. For a full representation of all techniques and trials, refer to Appendix 2. The spectrogram begins when sound begins, or the initiation of the transient, until the peak is reached, or .5 seconds (whichever occurs first). In these figures, intensities are represented on the color spectrum (ROYGBIV: Red-Orange-Yellow-Green-Blue-Indigo-Violet) where the most intense signals are a dark red, decreasing down to violet.
In general, most euphonium transients displayed a strong fundamental, or low harmonic, depicted by dark reds at the bottom-left of the figure. This fundamental, strengthened into a darker hue, and harmonics above it grew unit reaching the steady state. The time the sound samples took to display steady harmonic content, was similar to the EAT recorded in the previous section for each trial, suggesting the harmonic growth and establishment of the note is mostly linked to the growth of the sound in general.

Figure 4.12 displays trials this gradual growth in harmonic content, beginning with the fundamental. A blue line traces this growth pattern.
As with the qualitative and quantitative analysis, Techniques 1 and 5 showed similar harmonic content. Previous analysis techniques noted the precipitous growth of these techniques, as compressed air was quickly released. As seen in Figure 4.13, the fundamental grows quickly, but importantly, higher frequency overtones appear sooner, and before middle frequencies. This transient area is compared with the Control in Figure 4.13, and the discussed area is circled in blue.
Although less apparent than the comparisons among Techniques 1 and 5, the breath attacks, Techniques 3 and 4, show similarities. In Figure 4.14, a subtle, similar growth of harmonics is seen during the transient, compared to the fundamental.
As with harmonic analysis for the euphonium articulation techniques, harmonic analysis for selected phonemes strengthened similarities within previously detected phoneme groups. The harmonic growth of each transient did not occur in a uniform matter, as it mostly did for euphonium articulation. As previously noted, the general shapes of the envelope, VAT, and slope measurements vary, the resulting growth of harmonic content was affected and varied. Harmonic content is an integral component of defining timbre, and is thus a useful component for comparing and evaluating articulation techniques.

In one phoneme group mentioned before, voiceless, affricate, fricate, and nasal consonances, where the growth of the transient was hindered by the formation of the
consonant, harmonic content was stifled, spread, and erratic. In the phoneme pairings, plosives of each articulation location were included as a voiced and voiceless phoneme. For example, phonemes /pa/ and /ba/ are both plosives with labial articulators; however, /ba/ is voiced and /pa/ is voiceless. In each of these pairings (e.g. /p/ and /b/, /t/ and /d/, and /k/ and /g/) the voiceless phonemes and voiced phoneme groups each displayed similar characteristics. The voiced plosive phonemes (e.g. /b/, /d/, and /g/) displayed a full growth of harmonic and fundamental almost immediately. Conversely, during the articulation of voiceless plosive phonemes (/p/, /t/, and /k/), harmonic content was less intense, with a greater portion of higher fundamentals sounding more intensely, compared to the fundamental, than their voiced plosive counterpart. Figure 4.15 displays this phenomena, where voiced plosive /b/ activates stronger and more even harmonic content than its voiceless counterpart /p/.

Figure 4.15. Transient Spectrogram of Phonemes /p/ (top) and /b/ (bottom)
Vowel transient spectrogram readings were similar to each other, and also closely related to voiced plosives. Figure 4.16 displays the harmonic content of the transient for /ɑ/, /u/, and /r/.

These phonemes are similar because there is an immediate, strong, presence of developed harmonic content. Although it may appear that the spectrogram of /u/ has less uniform harmonics, because there are lower intensity readings between 1000HZ and 1400Hz, this is expected. The formants of /u/ are about 250Hz above the fundamental, and it is expected that a defining characteristic of this vowel is a lower intensity in that range.\(^\text{201}\)

Figure 4.16 displays a spectrogram of the entire sound clip with a logarithmic range, showing that, as expected for /u/, there is a formant strength between $10^3$Hz and $10^4$Hz.

![Figure 4.16. Spectrogram of Entire Recording of Phoneme /u/, With Logarithmic Scale](image)

Thus, anticipating that the content of these two phonemes is going to be innately different, each grows to its full strength almost immediately. The rhotic, or semivowel, /r/, again displays similarities of both vowel and consonant. Just as the envelope was slightly affected by the consonant, the harmonic content is also slightly altered. Figure 4.15 displays the transient spectrogram where a lower intensity of harmonics between 600 and 1000Hz is evident.

Phonemes /s/ and /ʧ/ exhibit similar unique characteristics. When the vocalist produces /s/, he/she mostly occludes the airflow with the tongue, letting a small, fast stream of air rush past. Similarly, the affricate /ʧ/, elongates this motion when tongue partially occludes, and slowly retreats in position back to the vowel. This characteristic, turbulent airflow, manifests itself in the harmonic component. The spectrograms of the transients, as seen in figure 4.17, display a high intensity of very high frequency sounds during the formation of the consonance.
Figure 4.18. Transient Spectrogram of /ʃ/ (top) and /s/ (bottom)
CHAPTER 5: CONCLUSION

In the previous chapter, data findings for euphonium and vocalist were discussed separately. Techniques and phonemes were grouped based on the similarities of pertinent data. Quantitative measures such as attack time, slope measures, and harmonic analysis were interpreted into performance applications. In addition, this chapter will discuss how these groupings related between voice and euphonium. The results suggested alternative pedagogical and performance tactics.

The mechanics of producing articulation on euphonium or other brass instruments are innately different than mechanics of vocal articulation. For this reason, it is impossible, as well as inconsequential, to pair each euphonium articulation technique with a corresponding phoneme. Rather, a continuum for euphonium and voice was identified. For example, groupings of phonemes and groupings of articulations can be arranged on a set of values. This set of values can either identify harmonic content, or timbre, and arrange articulation techniques or phonemes ranging from timbres with a concentration of intense low frequencies (often referred to as “dark” timbres) down a continuum to those with a concentration of intense high frequency overtones, which are often referred to as “bright” timbres. Additionally, the slope measure, or attack time, was understood as how sudden or gradual an articulation or onset appears. This was displayed on a continuum of sudden, immediate, or explosive articulations, referred to as “hard”, ranging to gradual or “soft” articulations. Using this model, later comparisons of euphonium articulation techniques and vocal techniques were made based upon where they each lie on these continuums.
Comparison and Interpretation of Euphonium Articulation Techniques

Using this approach, the first continuum interprets the qualitative measure of analyzing the shape of envelope, the quantitative findings of Euphonium Attack Time (EAT), and slope measurements into a descriptive hardness of articulation. Waveforms that displayed an explosive or precipitous incline or displayed a figure which peaked, then declined into a sustain, are interpreted as having a “hard” articulation. This corresponds to the quantitative findings. If a technique yielded a short EAT and/or a comparatively high value slope, a “hard” articulation is interpreted. Conversely, waveforms showing a comparatively gradual increase, combined with a longer EAT and lower value slope measurement, will be interpreted as a “soft” articulation.

<table>
<thead>
<tr>
<th>5</th>
<th>1</th>
<th>2b</th>
<th>Control</th>
<th>3</th>
<th>2a</th>
<th>2c</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Hard”</td>
<td></td>
<td></td>
<td>“Soft”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.1. Continuum of Euphonium Articulation Techniques Ranging from “Hard” to “Soft”

Figure 5.1 arranges these findings. The number in the top row refers to the technique assigned to the subject in Chapter 3. Space was inserted to indicate a greater degree of difference than a neighboring technique number. Again, Techniques 1 and 5 are grouped together. Figures 4.3 and 4.4 show similar abrasive waveforms, that increase precipitously and settle into a sustain. The techniques yielded very short EAT and the greatest slope measures. The second grouping, Techniques 2b, Control, 3, and 2a, displayed a moderate amount in each measure. These waveforms, while increasing precipitously, sustained at the peak of the transient, indicating that the articulation was not explosive. Additionally, EAT was more moderate, within a range of 1.5ds to 2.2ds.
Techniques were arranged, not just on quantitative measures of average EAT and slope measurement, but also by taking into consideration the shape of the envelope. The last grouping, Techniques 2c and 4, displayed a more gradual transient in the envelope or waveform reading. They also measured a longer average EAT, specifically, an EAT greater than 3ds and the lowest slope measurements.

A surprising interpretation of the data is the placement of Techniques 3 and 2c. The overwhelming majority of pedagogical and method texts admonished the practical use of breath attacks, claiming they were difficult to control, suggesting that the note “sneaks” into the sustain. This study found that utilizing a breath attack into an embouchure that has already been formed can yield an almost exact envelope formation, EAT, and slope measurements as traditional pedagogical techniques, such as 2a, and 2b. Additionally, the presumption that an articulation Technique 2c, that produces an occlusion in the mouth with the tip of the tongue on the inside of the upper lip would greater resemble other techniques that also occlude airflow in the mouth, but from slightly different locations, such as 2a and 2b. A repeated study where the ADSR reading was less skewed, as discussed in Ch. 4, may produce findings that display more similar characteristics between techniques 2a-c.

For euphonium articulation techniques, a similar continuum was created to represent timbre. As previously mentioned, a greater collection of low frequency, or fundamental frequency, corresponds to a “dark” timbre. Conversely, a collection of higher frequencies, or overtones, corresponds to a “bright” timbre. In Figure 5.2, euphonium articulation techniques are arranged, in the same manner as with Figure 5.1 on this continuum.
Figure 5.2. Continuum of Euphonium Articulation Techniques Ranging from “Dark” to “Bright”

The techniques that displayed the darkest timbre were the breath attack techniques (Techniques 3 and 4). In this continuum, all differences were more minute than the findings in Figure 5.1. Figure 4.14 shows that the harmonic spectrum for Techniques 3 and 4 is more full from the beginning, with a strong fundamental, justifying their placement in the “Dark” part of the continuum. The middle techniques, whose spectrograms are shown in Figure 4.12, display the similar trend of a moderately strong fundamental from the beginning, and the steady growth of fundamentals stretching upward from the fundamental. The brighter timbres, Techniques 4 and 5 shown in Figure 4.13, show a greater intensity of high frequencies, and on some trials, show lower intensities of middle frequency sounds.

**Comparison and Interpretation of Phonemes**

Vocal phonemes are arranged in the same manner, ranging from “hard” to “soft.” Similarly, phonemes which exhibited a strong growth pattern in the envelope, phonemes that peaks above the sustain point, phonemes that contain a fast Vocal Attack Time (VAT), and/or phonemes that exhibit a high value slope measurement, are interpreted as having a “hard” articulation. Conversely, phonemes which exhibited a gradual growth in the envelope, have a higher VAT, and/or a lower value slope measurement, are interpreted as having a “soft” articulation. For vocal phonemes, one additional
consideration must be made. As noted in Figure 4.8, voiceless plosives, fricative, and affricate consonance display unique envelope readings. The consonant is muted during the deadened formation of the consonant, while intraoral pressure builds. When the air is released and the vowel sounds, there is explosive growth in the envelope. This trend of jagged growth is thus interpreted as having a “hard” articulation. The results of this continuum are displayed in Figure 5.3.

<table>
<thead>
<tr>
<th>/p/</th>
<th>/k/</th>
<th>/t/</th>
<th>/ʃ/</th>
<th>/n/</th>
<th>/s/</th>
<th>/g/</th>
<th>/d/</th>
<th>/b/</th>
<th>/u/</th>
<th>/o/</th>
<th>/r/</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Hard”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.3. Continuum of Vocal Articulation Phonemes Ranging from “Hard” to “Soft”

For phonemes, more emphasis was given to the envelope shape. Mechanics for articulating phonemes are different for voice. The formation of certain consonances, particularly voiceless consonances, delays the propagation of vibration, which elongates the VAT, skewing the calculation of the range, making the figure seem as though the articulation is more gradual, or soft. This arrangement should be mostly apparent to one who speaks these syllables out loud. It is not surprising that voiceless plosives, such as /p/, /k/, and /t/ are the hardest, as previously discussed. The second grouping contains a mix of phoneme types, all of which are voiced. Phonemes /ʃ/, /n/, and /s/, all partially occlude airflow, then quickly release into the vowel. These phonemes display the muting during the vowel followed by explosive growth, characteristic of voiceless plosives, but to a lesser degree. VAT are influenced by this characteristic, and thus most comparison was made by analyzing the envelope.

A voiced plosive, /g/, is included in this grouping. Although it is voiced, the envelope reading shared more resemblance to the groups with partial or complete
occlusions. As observed with Technique 5 for brass, the action of occluding air by
making contact with the blade of the tongue against the velar region of the mouth, creates
a tumultuous perturbation in the air. Thus, even a voiced phoneme resembles the hard,
explosive growth of voiceless phonemes.

Next, two voiced consonances, /d/ and /b/ are deemed softer. Although the VAT
and slope for these phonemes suggests that these are hard articulation types, the envelope
refutes that. Both envelopes sustain after the initial peak, and grow quickly because they
are being voiced through the consonant. Not surprisingly, the softest phonemes are
vowels and the semivowel, /r/. The gradual growth of the transient is observed in both the
envelope reading and in the recorded VAT and slope measurement. The phoneme /u/, has
a shorter VAT than /ɑ/, explaining its placement. The most gradual is the semivowel, /r/,
which gradually delays the articulation by gliding into the vowel placement. The
envelope displays this gradual assent, and the VAT measure confirms that the transient
takes place over a longer period of time, 3.2ds.

A timbre continuum of vocal phonemes was created from the same criteria as the
brass articulation technique continuum. The results are displayed in Figure 5.4.

<table>
<thead>
<tr>
<th>/a/</th>
<th>/ɑ/</th>
<th>/ı/</th>
<th>/g/</th>
<th>/d/</th>
<th>/b/</th>
<th>/ɾ/</th>
<th>/p/</th>
<th>/k/</th>
<th>/ı/</th>
<th>/ʃ/</th>
<th>/s/</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Dark”</td>
<td>←</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>“Bright”</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.4. Continuum of Vocal Phonemes Ranging from “Dark” to “Bright”

The vowel phonemes differentiated from the rest as having the greatest, and most
immediate concentration of intense fundamental, without any distortion of high
frequency overtones, often created by consonances. This is evident in the spectrogram
depicted in Figure 4.15. As expected, the next group of consonances strongly contained
the fundamental, but to a lesser degree. As seen in Figure 5.5, phonemes /n/ and /g/,
contained the fundamental with little to no high overtones, creating a darker timbre.
Voiced plosives /d/ and /b/ both developed full harmonic spectrums quickly, with strong
fundamentals. These phonemes exhibited even development of harmonics. Phonemes /t/,
/p/, and /k/ began to exhibit bright characteristics by eliciting a combination of a muted
fundamental, along with a comparatively higher collection of high frequency sounds. For
example, a collection of overtones ranging from 4,000Hz to 9,000Hz is observed during
the transient for the /k/ phoneme. The brightest grouping, /t/, /ʧ/, and /s/, similarly
elicited a high concentration of very high frequency overtones, 5,000Hz to 10,000Hz, but
with little to no activation of the fundamental frequency.

**Comparison of Brass Techniques and Vocal Phonemes**

Regardless of whether or not one believes that a codification between brass
articulations and techniques and vocal phonemes should exist, comparison between some
techniques and phonemes have yielded convincing comparisons. It is up to the performer
to decide if he or she should use these styles to try to mimic words. Comparison to vocal
sounds may also prove to be a useful teaching tool for brass pedagogues.
A selection of phonemes can be eliminated from this comparison based on two criteria. One, their envelope reading exhibits characteristics that in no way resemble the envelope of brass articulation techniques. Two, the consonant in the phoneme represents multiple movements. Because no brass technique yielded an envelope in which the beginning of the transient was mostly muted, phonemes that exhibited this phenomena, such as voiceless plosives (/p/, /t/, and /k/), nasal (/n/), fricative (/s/), and affricate (/ʃ/)
consonances can be discounted from comparison. Additionally, when a singer produces a semivowel, such as /r/, there is a blended movement between the consonance and vowel. This movement is not characteristic of a euphonium or brass articulation which tries to center a single pitch. Although undesirable, if a comparison was to be made, the way that vowel was delayed in the phoneme /r/ displayed similarities to Technique 4, where the valve was simultaneously compressed while executing a breath attack. Figure 5.6 displays these similar envelope shapes.

Figure 5.6. Envelope Comparison of Technique 4.2 and Phoneme /r/

It is of note there was not a strong relation between Technique 5 and the phoneme /g/. Both sounds are created by exhaling against an occlusion created by the blade of the tongue against the velar region. Both exhibited a fairly precipitous, uneven, incline in the envelope. However, the shape of the envelope of /g/ was still significantly delayed by the consonance, increasing the VAT and decreasing the slope measure. Also, the phoneme
“g” was comparatively dark, while the corresponding euphonium articulation techniques was one of the brightest.

Voiced plosives /b/ and /d/ compared well to articulation Techniques 2a and 2b. Both phonemes and techniques are in the moderate range of both continuums for the hardness or softness of articulation and for timbre. Figure 4.2 displays an indicative envelope for Technique 2a. There is a sharp incline, which levels off into the sustain. Similarly, Figure 4.7 displays this same shape. Both spectrograms show that there is strong propagation of the fundamental frequency with some harmonics above, as seen in Figures 4.12 and 4.15. The envelope of these phonemes also compared well to Technique 3. Figure 5.7, displays that Technique 3 and the phoneme /b/ have very similar envelope shapes. Again, this is surprising that a breath attack counters the pedagogical writings, and suggests that it can be utilized to obtain a fast response. However, when analyzing the spectral components, there is not as strong of a relationship. The breath attacks, Techniques 3 and 4, exhibited very dark articulation types, with strong full fundamental frequencies, and a quick developing harmonic series above. This did not correspond to the brighter articulation recorded by the voiced plosives /b/ and /d/. However, this does add further credibility to the notion that breath attacks may be used as affectively as techniques involving the tongue, such as Techniques 2a and 2c.
While Technique 3 more strongly resembles the vowels /a/ and /u/. Both articulations grew fairly precipitously, and the transient lasted approximately 1ds. However, the strongest linking comparison is in the spectrogram reading. The breath attack techniques were the lone examples of euphonium articulation techniques that strongly established the fundamental frequency and immediately propagated strong overtones above. Figure 5.8, compares these trials and shows this strong similarity in harmonic growth.
Applications to Brass Pedagogy

Although there are many texts that espouse that a brass performer should try to emulate the human voice, it is ultimately the decision of the individual performer to decide if, or to what extent, he or she wants to mimic the voice. If the performer tries to strictly mimic voice while performing vocal transcriptions, the results of this study suggest that the performer can adapt his or her articulation technique to closely mimic certain phonemes. For example, if performing a song that starts on a vowel, such as Stefano Donaudy’s *O’ del mio amato ben* the results of this study suggest that using a breath attack will mostly accurately mimic the sound of the vowel on the entrance. Similarly, voiced consonances relate strongly to Techniques 2a and 2b and should be considered.

If the performer does not choose to use the findings to influence articulation choices while performing vocal transcriptions, there are other applications of this study. Knowing the comparative qualities of articulations types will influence their use. For
example, this study shows that creating a seal that compresses air and releasing it quickly (Technique 1), does not yield results that relate to any vocal sound collected in this study. Additionally, because of the explosive nature of the envelope that extends past the sustain point, this articulation technique can be explained as explosive. For most classical music genres, this is best avoided.

Additionally, if a performer desires a softer articulation, but does not feel comfortable using a breath attack, he or she could consider using Technique 2c. Simultaneously releasing air while articulating the tip of the tongue with the inside of the lip, created a more gradual growth in the envelope reading and a greater articulation time. Additionally, this technique was similar to other tongued techniques, relating to timbre, legitimizing its use. The results of this study do not suggest the use of Technique 4. Although this technique sought to create a more strident articulation by combining the exhale with the external impetus of compressing a valve, the opposite effect was found. The depression of the valve interrupted the airflow and ultimately prolonged the articulation.

Possible Further Studies

In addition to the additional parameters and limitations addressed in Chapter One, the process of this study revealed potential derivative studies. One particular educational benefit is of note. In Chapter 2 of this study, many pedagogues advocated teaching articulation by saying “Ta” or “Da”, interchanged. Different pedagogues did not differentiate between the use of the two, as they both articulate using the tip of the tongue to make contact with the dental/alveolar area. However, this study showed that there are drastic differences in the envelope shape and harmonic content of the two phonemes. It
may be interesting to note the differences of teaching modeling voiced phonemes exclusively, as they exhibit a more ideal, uniform envelope structure and timbre.

This study assumed that fundamental frequency modulations, or changes in pitch during the articulation, were user influenced. Meaning, that if there was a slight fluctuation in pitch during the articulation, it was assumed that it was an error attributed to the performer. Using a pitch detecting algorithm in a future study may further describe articulation techniques. If certain techniques consistently do not enter on the desired pitch, and must adjust up or down to the correct pitch, they are less useful to the performer. Knowing these affects could further credit or discredit certain articulation techniques.
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Appendix 1

Vocal Mechanisms and Anatomy

Voice production can be summarized into four major stages.

1. Inhalation.
2. Air is expelled from the lungs.
3. Expelled air creates vibrations as it moves across the vocal folds. These vibrations create sound waves.
4. Sound waves are manipulated by physical alterations in the vocal tract, mouth, and lips, to change and define properties of the sound.

Sound creation by the human voice and by brass instruments relies with the same mechanism: respiration. The diaphragm is a large dome-shaped muscle located beneath the lungs. When the diaphragm contracts, it moves downward and away from the lungs. This creates lower pressure in the lungs, causing air to move into the lungs, and beginning the respiration process. Intercostal muscles located between the bones in the rib cage, stabilize the shape of the ribs during this process. During exhalation, a combination of the weight of distended bones and muscles and the muscular exertion of a group of muscles, move air out of the lungs. The main muscles used in exhalation are the rectus abdominis, transversus abdominis, and the internal and external oblique muscles, displayed in figure 6.1.²⁰²

Figure 6.1. Muscles Involved in Respiration  
McConnell, fig. 1.7

The expelled air passes through the larynx, an organ located at the base of the neck which involves at different times breathing, sound production, and protecting the trachea against food aspiration. The figure below shows an outside view of the larynx. The displayed muscles below provide structure and protection for the larynx.

Figure 6.2. Structures Providing Support to Larynx  
Deidre, fig. 4
The thyroid cartilage sits over the cricoid cartilage and can often be identified as the “Adam’s Apple”. Pictured below from a vertical perspective, the arytenoid cartilages connect to the vocal folds. The arytenoid cartilages are connected to a system of muscles that manipulate the shape of the vocal folds which create different vibratory patterns.

![Figure 6.3. Vertical View of Glottal Opening and Surrounding Muscles](Image)

Deidre, fig. 6

The area or plane between the vocal folds is the glottis. When the vocal folds adduct, the glottis closes; conversely, when the vocal folds abduct, the glottis opens. In order for the vocal folds to vibrate, the folds must approximate a proper amount of tension. The posterior cricoarytenoid muscles open the glottis by pulling the back ends of the arytenoid cartilages together. The vocal folds are attached to these ends and are pulled apart. The opposing muscle pair is the lateral cricoarytenoid muscles, which adduct the glottis by pulling the back end of the arytenoid cartilages apart. This reverses the action and pulls the ends together, making the vocal folds come together. The folds alternatively trap air beneath an adducted glottis, and release it. Thus, these muscle pairs are responsible for the onset and release (offset) of vibration.
The folds manipulate pitch, or frequency of vibration, by lengthening and shortening the vibrating surface of the folds. The thyroarytenoid muscles contract themselves and work to shorten the vibrating surface. The thyroarytenoid muscles shorten the vocal folds by pulling the arytenoid (back) end of the vocal folds toward the thyroid (front) end. This shortens the vocal folds and bunches them up, which causes them to vibrate more slowly, thus lowering pitch. The thyroarytenoid muscles also have a force to strengthen glottic closure. That is, they help bring the vocal folds together and keep them together to resist the airstream from the lungs.203

Conversely, the cricothyroid muscles lengthen the thyroid cartilage and lengthen the vibrating surface, causing faster vibrations. This raises the pitch of resulting sound.

Pitch and intensity are manipulated by these muscles. If the folds are held together tightly, the subglottic pressure increases. Miller, shown in figure 6.5, states that “higher subglottal pressure corresponds to higher sound intensity; lower subglottic pressure corresponds to lower sound intensity”.204

![Figure 6.5. Registration of esophageal pressure during repeated vocal onsets, with breath after each triplet figure. “A” indicates high subglottic pressure and sound intensity; “B” indicates lower esophageal pressure and sound intensity; “C” indicates quick inspiration between triplet figures.](image)


Vocal folds vibrate on multiple three-dimensional surfaces at different tensions. Figure 6.6 displays the layers and thicknesses of the folds.

These vibrations travel up past the pharynx, the area located above the larynx that acts as a valve and directs materials down the esophagus to the stomach or air through the larynx. If one was to hear these vibrations as they came out of the larynx, they would sound like a buzz.\(^{205}\)

The manipulations and anatomy of the oral cavity, jaw, tongue, teeth, and lips, are discussed in Chapter 3, “Selection of Phonemes Used”. The resonance of the sound is manufactured by the openness and lack of tension in the back of the throat. The roof of

the mouth is referred to as the palate. It is divided into a hard area, which is located at the front of the mouth, and the soft, which is located in the back near the tonsils.
Appendix 2

Complete Audio Analysis Figures

Figure A2.1. Control, Trial 1
Figure A2.2. Control, Trial 2
Figure A2.3. Control, Take 3
Figure A2.4. Technique 1, Take 1
Figure A2.5. Technique 1, Trial 2
Figure A2.6. Technique 1, Trial 3
Figure 2A.7. Technique 2A, Trial 1
Figure 2A.8. Technique 2A, Trial 2
Figure 2A.9. Technique 2A, Trial 3
Figure 2A.10. Technique 2B, Trial 1
Figure 2A.11. Technique 2B, Trial 2
Figure 2A.12. Technique 2B, Trial 3
Figure 2A.13. Technique 2C, Trial 1
Figure 2A.14. Technique 2C, Trial 2
Figure 2A.15. Technique 2C, Trial 3
Figure 2A.16. Technique 3, Trial 1
Figure 2A.17. Technique 3, Trial 2
Figure 2A.18. Technique 3, Trial 3
Figure 2A.19. Technique 4, Trial 1
Figure 2A.20. Technique 4, Trial 2
Figure 2A.21. Technique 4, Trial 3
Figure 2A.22. Technique 5, Trial 1
Figure 2A.23. Technique 5, Trial 2
Figure 2A.24. Technique 5, Trial 3
Figure 2A.25. Phoneme /a/
Figure 2A.26. Phoneme /r/
Figure 2A.27. Phoneme /u/
Figure 2A.28. Phoneme /b/
Figure 2A.29. Phoneme /d/
Figure 2A.30. Phoneme /g//
Figure 2A.31. Phoneme /p/
Figure 2A.32. Phoneme /t/
Figure 2A.33. Phoneme /k/
Figure 2A.34. Phoneme /n/
Figure 2A.35. Phoneme /s/
Figure 2A.36. Phoneme /ʧ/