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Study of the Resonance Spectrums of the Flute and the Effect of Different Stable Vowels on Formant Tuning with Violin and Clarinet

Alyssa M. Schwartz

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A Study of the Resonance Spectrums of the Flute and the Effect of Different Stable Vowels on Formant Tuning with Violin and Clarinet

Alyssa M. Schwartz

This research document submitted
to the College of Creative Arts
at West Virginia University

in partial fulfillment of the requirements for the degree of
Doctorate of Musical Arts

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Spectrum

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Abstract

A Study of the Flute's Resonance Spectrum and the Effect of Different Monophthongs on Formant Tuning with Violin and Clarinet

Alyssa M. Schwartz

“In the long history of scientific investigation of musical instruments, the flute has been given particular attention, primarily because of its apparent simplicity. Yet many of the physical factors that determine its behavior have not been well documented.”¹ This is especially true when it comes to modern understanding of the way in which changes in the shape of the oral cavity affect the resonance spectrum of the flute.

Creating different monophthongs, or stable-vowel positions, while playing the flute changes the spectral slope and strength of the overtones in the flute tone. This affects the ability of the flute to successfully blend with other instruments. This concept is known as formant tuning, or the deliberate adjustment of the strength of the different overtones in a sound. This study is the first to record, measure, and analyze the changes that will occur in the resonance spectrum of the flute when a tone is produced through different monophthongs.

This study provides an analysis of four pitches that cover all three registers of the flute and clarinet and the four strings of the violin as performed on the C Flute (E4, C5, A5, and G6) using the software VoceVista. Three flutists were asked to record each pitch while creating the following six monophthongs:

- [i] (as heard in “sheep” and “me”)
- [ɪ] (as heard in “mit” and “him”)
- [ə] (the Schwa position as heard in “father” and “comma”)
- [ʊ] (as heard in “put” and “foot”)
- [u] (as heard in “goose” and “soup”)
- [ɔ] (as heard in “thought” and “brought”)

The resonance spectra of each pitch in each position have been recorded, analyzed, and compared with the spectra of the same pitches as played by a group of violinists and a single clarinetist. Suggestions based on these spectra are provided as to which monophthongs on the part of the flutist will yield a higher or lower homogeneity of blend with the violinists and clarinetist in the different registers of the instruments.

¹Coltman, John W. “Acoustics of the Flute,” *Physics Today*, no. 21 [1968]: 25.

Dedication

To my parents, Steve and Laurel Schwartz, whose unending support and love have made me the woman I am today, my husband, life partner, and best friend Richard Schwartz, and the woman who taught me to love the flute, Nicole Zenns.

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TABLE OF CONTENTS

DEDICATION	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF TABLES	vii
LIST OF FIGURES	viii
LIST OF AUDIO FILES	xi
INTRODUCTION.....	1
CHAPTER I: VOWELS.....	6
DEFINITION	6
PHONETICS AND PHONOLOGY	7
CLASSIFICATION OF VOWELS: MONOPHTHONGS, DIPHTHONGS, AND TRIPHTHONGS	8
CLASSIFICATION OF VOWELS: THE CARDINAL VOWEL SYSTEM	8
THE INTERNATIONAL PHONETIC ALPHABET	11
MONOPHTHONGS INCLUDED IN THIS STUDY	12
CHAPTER II: FORMANT TUNING.....	17
HARMONICS	17
FORMANTS	18
VOWEL FORMANTS	19
FORMANT REGIONS OF THE FLUTE	22
FORMANT TUNING	22
THE SINGER'S FORMANT	23
CHAPTER III: THE RESONANCE SPECTRUM OF THE C FLUTE.....	25
THE FLUTISTS	25
THE DISPLAYS OF VOCEVISTA	26
SAMPLE: RESONANCE SPECTRA OF E4 WITH [i] MONOPHTHONG	28
ANALYZING THE SPECTRA	30
CHANGES IN THE RESONANCE SPECTRA OF E4	31
CHANGES IN THE RESONANCE SPECTRA OF C5	33
CHANGES IN THE RESONANCE SPECTRA OF A5	35
CHANGES IN THE RESONANCE SPECTRA OF G6	37
CHAPTER IV: THE RESONANCE SPECTRUM OF THE VIOLIN AND CLARINET.....	39
THE MUSICIANS	39
ANALYZING THE SPECTRA	39
RESONANCE SPECTRA OF THREE VIOLINS	40
RESONANCE SPECTRA OF THE CLARINET.....	43
CHAPTER V: BLENDING: C FLUTE AND VIOLIN.....	46
ORCHESTRAL SUITE NO. 2 IN B MINOR, MOVEMENT V, "POLONAISE," BY JOHANN SEBASTIAN BACH.....	46
SYMPHONY NO. 92 IN G MAJOR, MOVEMENT II, BY JOSEPH HAYDN	47
SYMPHONY NO. 3 IN E-FLAT MAJOR, "EROICA," MOVEMENT IV, BY LUDWIG VAN BEETHOVEN	49

SYMPHONY NO. 5 IN D MINOR, OP. 47, MOVEMENT I, BY DMITRI SHOSTAKOVICH	51
FOUR SEAS INTERLUDES, MOVEMENT 1, “DAWN,” FROM PETER GRIMES, OP. 33A, BY BENJAMIN BRITTEN	53
CHAPTER VI: BLENDING: C FLUTE AND CLARINET.....	55
TARANTELLE FOR FLUTE AND CLARINET, OP. 6, BY CAMILLE SAINT-SAËNS	55
SYMPHONY NO. 2 IN D MAJOR, OP. 73, MOVEMENT IV, BY JOHANNES BRAHMS	58
CAPRICCIO ESPAGNOL, OP. 34, MOVEMENT IV, “SCENA E CANTO GITANO” BY NIKOLAI RIMSKY-KORSAKOV	61
CONCLUSION.....	63
APPENDIX 1.....	67
APPENDIX 2.....	116
BIBLIOGRAPHY	124

LIST OF TABLES

TABLE 3.1: RESONANCE SPECTRA OF E4 ON FLUTE WITH VARIOUS MONOPHTHONGS	31
TABLE 3.2: RESONANCE SPECTRA OF C5 ON FLUTE WITH VARIOUS MONOPHTHONGS	33
TABLE 3.3: RESONANCE SPECTRA OF A5 ON FLUTE WITH VARIOUS MONOPHTHONGS	35
TABLE 3.4: RESONANCE SPECTRA OF G6 ON FLUTE WITH VARIOUS MONOPHTHONGS	37
TABLE 4.1: RESONANCE SPECTRA OF THREE VIOLINS.....	40
TABLE 4.2: RESONANCE SPECTRA OF THE CLARINET	43
TABLE 7.1: VOWEL PLACEMENT FOR FLUTISTS FOR BLEND WITH VIOLIN AND CLARINET	64

LIST OF FIGURES

FIGURE 1.1: HUMAN VOCAL ORGANS	7
FIGURE 1.2: CARDINAL VOWEL SYSTEM	9
FIGURE 1.3: LOCATION OF [i]	13
FIGURE 1.4: LOCATION OF [ɪ]	14
FIGURE 1.5: LOCATION OF [ə]	14
FIGURE 1.6: LOCATION OF [ʊ]	15
FIGURE 1.7: LOCATION OF [u]	15
FIGURE 1.8: LOCATION OF [ɔ]	16
 FIGURE 2.1: RESONANCE SPECTRUM OF A SIMULATED SOURCE (SOURCE NOT AFFECTED BY ADDITIONAL RESONATORS)	18
FIGURE 2.2: RESONANCE SPECTRUM OF VOWEL [i]	20
FIGURE 2.3: VOWEL FORMANTS	21
FIGURE 2.4: RESONANCE SPECTRA OF SPEECH, ORCHESTRA, AND ORCHESTRA/VOCALIST	23
 FIGURE 3.1: THE DISPLAYS OF VOCEVISTA	26
FIGURE 3.2: E4, [i], ALBERTO ALMARZA	28
FIGURE 3.3: E4, [i], LINDSEY GOODMAN	28
FIGURE 3.4: E4, [i], ALYSSA SCHWARTZ	29
 FIGURE 5.1: POLONAISE FROM ORCHESTRAL SUITE NO. 2 BY J. S. BACH	46
FIGURE 5.2: EXCERPT FROM MOVEMENT II, SYMPHONY NO. 92 BY JOSEPH HAYDN	48
FIGURE 5.3: FLUTE SOLO FROM MOVEMENT IV, SYMPHONY NO. 3 BY LUDWIG VAN BEETHOVEN	50
FIGURE 5.4: EXCERPT FROM MOVEMENT I, SYMPHONY NO. 5 IN D MINOR BY DMITRI SHOSTAKOVICH	52
 FIGURE 6.1: EXCERPT FROM TARANTELLA FOR FLUTE AND CLARINET BY CAMILLE SAINT-SAËNS	56
FIGURE 6.2: EXCERPT FROM SYMPHONY NO. 2 IN D MAJOR, MOVEMENT IV BY JOHANNES BRAHMS	59
FIGURE 6.3: FLUTE/ CLARINET SOLO FROM CAPRICCIO ESPAGNOL BY NIKOLAI RIMSKY-KORSAKOV	61
 FIGURE A1.1: E4, [i], ALBERTO ALMARZA	68
FIGURE A1.2: E4, [i], LINDSEY GOODMAN	68
FIGURE A1.3: E4, [i], ALYSSA SCHWARTZ	69
FIGURE A1.4: E4, [ɪ], ALBERTO ALMARZA	70
FIGURE A1.5: E4, [ɪ], LINDSEY GOODMAN	70
FIGURE A1.6: E4, [ɪ], ALYSSA SCHWARTZ	71
FIGURE A1.7: E4, [ə], ALBERTO ALMARZA	72
FIGURE A1.8: E4, [ə], LINDSEY GOODMAN	72
FIGURE A1.9: E4, [ə], ALYSSA SCHWARTZ	73
FIGURE A1.10: E4, [ʊ], ALBERTO ALMARZA	74
FIGURE A1.11: E4, [ʊ], LINDSEY GOODMAN	74
FIGURE A1.12: E4, [ʊ], ALYSSA SCHWARTZ	75
FIGURE A1.13: E4, [u], ALBERTO ALMARZA	76
FIGURE A1.14: E4, [u], LINDSEY GOODMAN	76
FIGURE A1.15: E4, [u], ALYSSA SCHWARTZ	77
FIGURE A1.16: E4, [ɔ], ALBERTO ALMARZA	78
FIGURE A1.17: E4, [ɔ], LINDSEY GOODMAN	78
FIGURE A1.18: E4, [ɔ], ALYSSA SCHWARTZ	79
 FIGURE A1.19: C5, [i], ALBERTO ALMARZA	80
FIGURE A1.20: C5, [i], LINDSEY GOODMAN	80
FIGURE A1.21: C5, [i], ALYSSA SCHWARTZ	81
FIGURE A1.22: C5, [ɪ], ALBERTO ALMARZA	82
FIGURE A1.23: C5, [ɪ], LINDSEY GOODMAN	82

FIGURE A1.24: C5, [i], ALYSSA SCHWARTZ	83
FIGURE A1.25: C5, [ə], ALBERTO ALMARZA	84
FIGURE A1.26: C5, [ə], LINDSEY GOODMAN	84
FIGURE A1.27: C5, [ə], ALYSSA SCHWARTZ	85
FIGURE A1.28: C5, [u], ALBERTO ALMARZA	86
FIGURE A1.29: C5, [u], LINDSEY GOODMAN	86
FIGURE A1.30: C5, [u], ALYSSA SCHWARTZ	87
FIGURE A1.31: C5, [u], ALBERTO ALMARZA	88
FIGURE A1.32: C5, u], LINDSEY GOODMAN	88
FIGURE A1.33: C5, [u], ALYSSA SCHWARTZ	89
FIGURE A1.34: C5, [ə], ALBERTO ALMARZA	90
FIGURE A1.35: C5, [ə], LINDSEY GOODMAN	90
FIGURE A1.36: C5, [ə], ALYSSA SCHWARTZ	91
FIGURE A1.37: A5, [i], ALBERTO ALMARZA	92
FIGURE A1.38: A5, [i], LINDSEY GOODMAN	92
FIGURE A1.39: A5, [i], ALYSSA SCHWARTZ	93
FIGURE A1.40: A5, [i], ALBERTO ALMARZA	94
FIGURE A1.41: A5, [i], LINDSEY GOODMAN	94
FIGURE A1.42: A5, [i], ALYSSA SCHWARTZ	95
FIGURE A1.43: A5, [ə], ALBERTO ALMARZA	96
FIGURE A1.44: A5, [ə], LINDSEY GOODMAN	96
FIGURE A1.45: A5, [ə], ALYSSA SCHWARTZ	97
FIGURE A1.46: A5, [u], ALBERTO ALMARZA	98
FIGURE A1.47: A5, [u], LINDSEY GOODMAN	98
FIGURE A1.48: A5, [u], ALYSSA SCHWARTZ	99
FIGURE A1.49: A5, [u], ALBERTO ALMARZA	100
FIGURE A1.50: A5, u], LINDSEY GOODMAN	100
FIGURE A1.51: A5, [u], ALYSSA SCHWARTZ	101
FIGURE A1.52: A5, [ə], ALBERTO ALMARZA	102
FIGURE A1.53: A5, [ə], LINDSEY GOODMAN	102
FIGURE A1.54: A5, [ə], ALYSSA SCHWARTZ	103
FIGURE A1.55: G6, [i], ALBERTO ALMARZA	104
FIGURE A1.56: G6, [i], LINDSEY GOODMAN	104
FIGURE A1.57: G6, [i], ALYSSA SCHWARTZ	105
FIGURE A1.58: G6, [i], ALBERTO ALMARZA	106
FIGURE A1.59: G6, [i], LINDSEY GOODMAN	106
FIGURE A1.60: G6, [i], ALYSSA SCHWARTZ	107
FIGURE A1.61: G6, [ə], ALBERTO ALMARZA	108
FIGURE A1.62: G6, [ə], LINDSEY GOODMAN	108
FIGURE A1.63: G6, [ə], ALYSSA SCHWARTZ	109
FIGURE A1.64: G6, [u], ALBERTO ALMARZA	110
FIGURE A1.65: G6, [u], LINDSEY GOODMAN	110
FIGURE A1.66: G6, [u], ALYSSA SCHWARTZ	111
FIGURE A1.67: G6, [u], ALBERTO ALMARZA	112
FIGURE A1.68: G6, u], LINDSEY GOODMAN	112
FIGURE A1.69: G6, [u], ALYSSA SCHWARTZ	113
FIGURE A1.70: G6, [ə], ALBERTO ALMARZA	114
FIGURE A1.71: G6, [ə], LINDSEY GOODMAN	114
FIGURE A1.72: G6, [ə], ALYSSA SCHWARTZ	115
FIGURE A2.1: E4, THREE VIOLINS	116
FIGURE A2.2: C5, THREE VIOLINS	117
FIGURE A2.3: A5, THREE VIOLINS	118

FIGURE A2.4: G6, THREE VIOLINS	119
FIGURE A2.5: E4, CLARINET.....	120
FIGURE A2.6: C5, CLARINET	121
FIGURE A2.7: A5, CLARINET	122
FIGURE A2.8: G6, CLARINET	123

LIST OF AUDIO FILES

AUDIO FILE 4.1: LINDSEY GOODMAN, [ʊ], AND VIOLINISTS, E4	40
AUDIO FILE 4.2: LINDSEY GOODMAN, [i], AND VIOLINISTS, E4	41
AUDIO FILE 4.3: ALBERTO ALMARZA, [ə], AND VIOLINISTS, C5.....	41
AUDIO FILE 4.4: ALBERTO ALMARZA, [I], AND VIOLINISTS, C5.....	41
AUDIO FILE 4.5: ALYSSA SCHWARTZ, [ɔ], AND VIOLINISTS, A5	41
AUDIO FILE 4.6: ALYSSA SCHWARTZ, [i], AND VIOLINISTS, A5	42
AUDIO FILE 4.7: LINDSEY GOODMAN, [ə], AND VIOLINISTS, G6.....	42
AUDIO FILE 4.8: LINDSEY GOODMAN, [ɔ], AND VIOLINISTS, G6.....	42
 AUDIO FILE 4.9: ALBERTO ALMARZA, [ə], AND CLARINETIST, E4.....	 43
AUDIO FILE 4.10: ALBERTO ALMARZA, [i], AND CLARINETIST, E4	44
AUDIO FILE 4.11: ALYSSA SCHWARTZ, [ə], AND CLARINETIST, C5	44
AUDIO FILE 4.12: ALYSSA SCHWARTZ, [ɔ], AND CLARINETIST, C5.....	44
AUDIO FILE 4.13: LINDSEY GOODMAN, [i], AND CLARINETIST, A5	45
AUDIO FILE 4.14: LINDSEY GOODMAN, [ʊ], AND CLARINETIST, A5.....	45
AUDIO FILE 4.15: ALBERTO ALMARZA, [u], AND CLARINETIST, G6.....	45
AUDIO FILE 4.8: ALBERTO ALMARZA, [I], AND CLARINETIST, G6.....	45

Introduction

“In the long history of scientific investigation of musical instruments the flute has been given particular attention, primarily because of its apparent simplicity. Yet many of the physical factors that determine its behavior have not been well documented.”² This is especially true when it comes to modern understanding of the way in which changes in the shape of the oral cavity affects the resonance spectrum of the flute. The resonance spectrum measures the strength of overtones, which the listening ear perceives as the timbre, or color, of the sound. Creating different monophthongs, or stable-vowel positions, while playing the flute affect the strength of the overtones in, or the timbre of, the flute tone. This is significant because a change in the flute’s resonance spectrum will affect the flute’s ability to successfully blend with other instruments due to formant tuning, or the deliberate adjustment of the strength of the different overtones in a sound. However, there has not yet been a study that has sought to understand the changes that will occur in the resonance spectrum of the flute when a tone is produced through different monophthongs.

Blend when performing with other musicians has been an area of focus for flutists since the Baroque era, as evidenced by pedagogical writings addressing the issue, and it is a concern that still faces modern performers today. The current body of flute pedagogy tends, primarily, to emphasize adjusting the direction of the airstream with the lips or the alignment of the tone hole, increasing or decreasing the pressure of the airstream (that is, changing its velocity), and providing alternate fingerings that can adjust the intonation and resonance of the flute. While this instruction has evolved somewhat throughout the course of history as the science of sound, resonance, and tone production has become more widely understood, a largely-neglected aspect of flute playing that affects intonation still remains: a technical study of the effects creating different vowel positions while playing and their relation to the resonance spectrum of flute tone. Not only is this largely undiscussed in the fluting world today, but those written sources that do address this topic do so from a nontechnical perspective, as seen in the sources examined below, which include the most significant and representative works in the current body of flute pedagogical literature.

Baroque flutist, flute maker, and composer Johann Joachim Quantz advised principal flutists performing in orchestras “...the effect of a composition will always be considerably

²Coltman, John W. “Acoustics of the Flute,” *Physics Today*, no. 21 [1968]: 25.

impaired if the instruments are not in tune with one another. Hence if the leader wishes to maintain correct intonation in the performance of a musical composition, he must first tune his own instrument truly with the keyboard, and then have each individual instrumentalist tune to him.”³ He goes on to offer advice on how to utilize the different tenors available to flutists in this era to adjust their intonation and discusses the importance of weather and air speed when considering intonation and blend with other instruments. However, he does not discuss any mechanics of the inside of the oral cavity or the resonance spectrum of the flute, and the importance of this when it comes to blending with other instruments.

In the 19th century, German flutist Theobald Boehm invented the famous Boehm flute, as he sought to create an instrument that was proportioned based on acoustical properties as opposed to the limitations of human biology. He produced a treatise, *The Flute and Flute Playing*, which explained the principles upon which he built his instrument and offered instruction to flutists on how to successfully play the instrument. While he does offer instruction on how to adjust intonation (both through manipulation of the instrument itself and through physiological manipulations), he does not address issues of blend or resonance. Boehm advises flutists that the size of the embouchure and direction and pressure of the air stream will affect the intonation of the sound produced, but he does not go on to discuss the affect this may have on tone color or a flutist’s ability to blend with other instrumentalists.⁴

Yale flute instructor Thomas Nyfenger stresses the importance of being able to adjust tone color and intonation in his 1986 publication *Music and the Flute*, but makes no mention of the importance of blending with other instruments and offers no advice on how to manipulate the tongue in any other context than that of articulation. He, like many others, instructs flutists to be mindful of the shape and position of the lips, the angle of the airstream, and the amount to which the tone hole is or is not covered by the lips, when focusing on intonation. However, his advice on intonation stops here and does not address any issues of different vowels, resonance spectrum, formant tuning, or blend.⁵

³Quantz, Johann Joachim. *On Playing the Flute: The Classic of Baroque Music Instruction*. 1762. Trans. Edward R. Reilly. Boston: Northeastern University Press, 1966, 209-210.

⁴Boehm, Theobald. *The Flute and Flute Playing*. 1872. Trans. Dayton C. Miller. London: Rudall, Carte, & Co, 1922, 21.

⁵Nyfenger, Thomas. *Music and the Flute*. Paul Nyfenger, New Jersey, 1986, 19-21;

In his *The Simple Flute: From A to Z* written in 2010, French flutist Michel Debost, principal flutist of the Paris Orchestra and Professor at the Paris Conservatory, provides practical advice for flutists on intonation, tone quality, and blend, advising musicians to tune open fifths with the oboe or piano when playing in ensembles, practicing with a tuner while playing *forte* and *pianissimo*, practicing with a tuner for particularly unstable notes such as C#5 and C#6, and practicing with a tuner while using vibrato.⁶ While Debost does acknowledge that different vowel positions affect the quality of the flute's tone, he does not delve into any specifics on the manner in which manipulation of the tongue may affect the resonance spectrum of the instrument.

Flute historian Nancy Toff informs modern flutists that intonation "...is an integral part of tone production" in her work *The Flute Book: A Complete Guide for Students and Performers*.⁷ She opines that a flutist with an unfocused or spread tone quality is more likely to be out of tune with other musicians and blend poorly, while a resonant and centered tone is more likely to produce a well-tuned and blended player. Toff further goes on to offer flutists several suggestions on adjusting their tone color and resonance, including direction of the air stream as achieved by raising and lowering the head and adjusting the jaw, suggesting alternate fingerings to improve intonation for certain pitches, and adjustment in the speed of the air stream as achieved by changing the firmness of the diaphragm and lip pressure. She also warns that changing weather, temperature, and humidity can affect a flutist's intonation.⁸ However, her advice does not include information on the use of different vowel positions within the mouth to adjust tone color or blend.

A few sources do address the role of vowels in the production of flute tone, albeit topically. Famed performer James Galway is one of the few who directly broaches the subject of vowels when it comes to flute playing, saying "Bright colours are made by the more closed-up vowels said at the front of the mouth, dark colours by the vowels at the back."⁹ While many flutists may

⁶DeBost, Michel and Jeanne Debost-Roth. *The Simple Flute: From A to Z*. New York: Oxford University Press, 2010, 257.

⁷Toff, Nancy. *The Flute Book: A Complete Guide for Students and Performers*. Third Edition. New York: Oxford University Press, 2012, 100.

⁸Toff, *The Flute Book*: 101-102.

⁹Galway, James. *Flute*. New York: Schirmer Books, 1982, 97.

certainly be able to agree with this statement from personal experience, he does not offer any data to support this claim, and he does not explore in depth the relationship between different vowels and blend or resonance.

In his *Practice Book for the Flute Volume 4: Intonation and Vibrato*, English flutist Trevor Wye also acknowledges the importance of tongue placement and vowels while playing the flute, saying “Why do we hear a difference between two different flute players? Because the sound each player makes—though playing the *same* notes with the *same* harmonics—contains different *quantities* of each harmonic.”¹⁰ He goes on to stress the importance of refining the ear and being in tune with oneself, providing a number of exercises for students seeking to improve their intonation and ability to create different tone colors.

This reference is one of the few that directly acknowledges the notion that different timbres of flute tone may have different resonance spectra from one another, recognizing that the strength of the overtones may vary from one player to another. However, like the other standard flute pedagogical materials currently in existence, this source does not provide details on what the changes in spectra may look like or how they are achieved.

Though flute pedagogy throughout history has offered instruction on manipulating the embouchure and air stream in order to adjust the timbre of the tone and seek a successful blend when performing with other instruments, the body of instruction currently in existence tends to neglect the importance of the position of the tongue and the affect that different monophthongs have on the resonance spectrum of the flute. This study reveals how the manipulation of the oral cavity affects the flute’s resonance spectrum, or the proportional strengths of the harmonics in the sound, and therefore the timbre, by providing an analysis of four different pitches covering all three registers of the flute as performed with six different monophthongs. The timbre of the sound produced in each different vowel position on each pitch is discussed and analyzed, with brighter timbre being defined as a tone in which the higher harmonics of the sound are more strengthened and darker timbre being defined as a tone in which the higher harmonics of the sound are more damped. It is important to note that the use of vibrato while playing does not significantly affect the resonance spectra of the flute tone, so vibrato is not discussed in this study. Furthermore,

¹⁰Wye, Trevor. *Practice Books for the Flute*. London: Novello Publishing Limited, 1980, 121

suggestions as to which monophthongs will produce more or less homogeneity when blending with other instruments, specifically, the violin and clarinet, will be provided.

Chapter I provides a detailed analysis of the physical formation of the six monophthongs used in this study, showing the specific position of each part of the tongue when producing each monophthong. Chapter II provides an explanation of formants and formant tuning as related to this study. Chapter III provides information on the resonance spectra of 4 different pitches played on the C flute with the 6 different monophthongs as recorded through VoceVista. This section will also examine and compare any noticeable differences in the spectra as produced by the different positions. Images of the analyses by VoceVista are included in order to show the results. Chapter IV provides the resonance spectra of the 4 different pitches played on the violin and clarinet with the 6 different monophthongs as recorded through VoceVista. Audio files of these pitches combined with the audio files of the flutists as extracted from VoceVista and copied into one audio track will be provided through active links to YouTube clips in order to demonstrate the results. Conclusions as to which monophthongs will result in a higher or lower homogeneity of blend are provided. Chapters V and VI provide excerpts from orchestral literature in which the C Flute is required to blend with the violin and the clarinet in unisons and in octaves. These two chapters also provide conclusions as to which monophthongs will result in a higher or lower homogeneity of blend with respect to the different registers of the instruments. The conclusion provides a summary of which vowel positions on the part of the flutist will yield the highest level of blend with the violin and clarinet for each register of each instrument.

Chapter I: Vowels

Definition

Phonetically, a vowel is an element of human speech that is defined as a “sound in which the flow of air from the lungs passes through the mouth, which functions as a resonance chamber, with minimal obstruction and without audible friction.”¹¹ The vowel is contrasted with the consonant, which is “characterized by an articulation with a closure or narrowing of the vocal tract such that a complete or partial block of the flow of air is produced.”¹² Though the English alphabet and study of the written English language typically address only five main vowel sounds, there are in fact twenty vowel sounds producible in English with additional vowel sounds being found in other languages. The difference in sounds is produced by manipulation of the vocal organs, with the most important factors being the exact shape and position of the tongue and lips.¹³ Phonologically, vowels are the sounds most typically found mid-syllable and are often surrounded by consonants.¹⁴

Vowels, and all elements of human speech, are created through engagement and manipulation of the vocal organs. Figure 1.1 on the following page provides an anatomically-correct diagram of the human organs of articulation. This diagram does not show all human vocal organs, as the lungs and diaphragm are not included, but pictures the organs of articulation, or speech organs, including the glottis, larynx, pharynx, uvula, hard and soft palates, tongue, alveolar ridge, teeth, lips, and nose. The different parts of the tongue in the diagram are as follows: 1) tip, 2) blade, 3) front, 4) center, and 5) back.¹⁵

¹¹*Encyclopedia Britannica Online*, s.v. “Vowel,” accessed February 14, 2018, <http://academic.eb.com/levels/collegiate/article/vowel/75766>.

¹²*Encyclopedia Britannica Online*, s.v. “Consonant,” accessed February 18, 2018, <https://www.britannica.com/topic/consonant>.

¹³Jones, Daniel. *An Outline of English Phonetics* [New York: G. E. Stechert & Co., 1922], 16.

¹⁴Crystal, David. *The Cambridge Encyclopedia of the English Language* [New York: Cambridge University Press, 1995], 236-7.

¹⁵Crystal, *The Cambridge Encyclopedia of English*, 236.

Figure 1.1: Human Vocal Organs¹⁶ (Used with permission)

Phonetics and Phonology

The production of human speech sounds may be examined from two basic perspectives: phonetics and phonology. Phonetics is the study of the way in which humans produce and receive auditory sounds and encompasses all possible sounds that can be physically produced. By contrast, phonology is the study of the sound system of different languages focusing more specifically on the way in which different sounds have meaning within a language (meaningful sounds are called *phonemes*). Square brackets [] are placed around the symbols used to depict speech sounds when the study is phonetic and slanted brackets / / are utilized when the study is phonological.¹⁷ The distinction here is important because this study, being concerned with the physical production of specific vowel positions, will approach the subject from a phonetic perspective.

¹⁶Crystal, *The Cambridge Encyclopedia of English*, 236.

¹⁷Crystal, *The Cambridge Encyclopedia of English*, 236.

Classification of Vowels: Monophthongs, Diphthongs, and Triphthongs

One system of classifying vowels is according to the motion, or lack thereof, of the tongue as the sound is being produced as well as by the exact position and shape of the tongue. Monophthongs, or pure vowels, are stationary and produced by air passing through an unchanging oral cavity (for example, the long-e sound in “heed”). Diphthongs, or gliding vowels, on the other hand, are created with constant change in the oral cavity, predominantly in the tongue (for example, the sound that “oi” combined make together in “coin”). Two vowels may be perceived in every diphthong.¹⁸ Triphthongs are a combination of three vowel sounds in which there is a central gliding vowel in the middle of a starting and ending vowel position, such as the combination heard in the word “fire.”¹⁹ Of the twenty vowel sounds in the English language, twelve are considered monophthongs and eight are diphthongs. Triphthongs are not universally considered true vowels in the English language due to the characteristic, consonant-like compression that occurs mid-triphthong.²⁰

It is important to note that only monophthongs will be utilized in this study as a relatively stable tongue position is utilized when producing traditional tone and consistent tone color in flute playing when producing a single pitch of unvarying dynamic. When playing a single pitch at a constant dynamic level, the use of an unstable tongue position, or diphthongs, tends to occur in flute playing only for articulation needs, producing tapers, and performing certain extended techniques.

Classification of Vowels: The Cardinal Vowel System

In 1918, British phonetician Daniel Jones published a comprehensive book, *An Outline of English Phonetics*, on understanding and producing all sounds of the English language with the purpose of assisting non-native English speakers in mastering the sounds of the language. In this

¹⁸Encyclopedia Britannica Online

¹⁹Crystal, *The Cambridge Encyclopedia of English*, 460.

²⁰Crystal, *The Cambridge Encyclopedia of English*, 236-239.

book, Jones introduced the Cardinal Vowel System, which is still the most widely-used and well-known system of classifying vowels today.²¹

The Cardinal Vowel System classifies vowels according to the position of each part of the tongue (front, center, and back) within the oral cavity.²² See Figure 1.2, the Cardinal Vowel (CV) Diagram, below.²³

Figure 1.2: Cardinal Vowel System (Used with permission)

“Front,” “Central,” and “Back” listed on the top of the diagram indicate the front, center, and back of the tongue, respectively. The forward most part of the tongue is the tip, followed by the blade. The front of the tongue is just behind the blade, opposite the hard palate, the back of the tongue is farthest back in the jaw and closest to where the tongue is anchored, across from the soft palate, and the center of the tongue is in between (Refer to Figure 1.1).²⁴ “Close,” “Close-mid,” “Open-mid,” and “Open” indicated on the left-hand side of the diagram denote the classification of each different position.

²¹Crystal, *The Cambridge Encyclopedia of English*, 238-239.

²²Jones, *An Outline of English Phonetics*, 17.

²³Crystal, *The Cambridge Encyclopedia of English*, 238.

²⁴Crystal, *The Cambridge Encyclopedia of English*, 236.

The symbols in this diagram were created by Daniel Jones for his classification system. It is sufficient to understand, at this time, that these symbols assist in identifying and labeling the different vowels according to the position of the different parts of the tongue.

The “a” symbol (the vowel heard in “son”), toward the mid-bottom of the diagram, represents the lowest position that the front-most part of the tongue can physically achieve through non-rounded lips, while the “ɑ” symbol to the right of this (the vowel heard in “thought” and “bought”) indicates the lowest position that the back-most part of the tongue can physically achieve through non-rounded lips. These positions are referred to “open” or “low” vowels. The “æ” and “ɒ” symbols, to the right of each of the aforementioned symbols, respectively, indicate the same vowel sound produced with rounded lips. Throughout the diagram, the symbols on the left-hand side of each point of classification refer the vowel as produced with non-rounded lips where the symbols to the right of these refer to the vowel as produced with rounded lips. For example, the front, close-mid vowel “e” refers to the vowel sound created with non-rounded lips (as heard in “bet”), where the symbol immediately to the right of this, “ø” indicates the same vowel position created with rounded lips (as heard in the first part of the vowel sound in “nurse”).

The “i” symbol (the vowel heard in “sea” and “feet”) indicates the highest position that the front of the tongue can maintain while still producing a vowel sound (again, through non-rounded lips), while the “ɪ” symbol indicates the same for the center of the tongue and the “u” symbol indicates the same for the back-most part of the tongue. These positions are referred to as “close” or “high” vowels.

The “e” (the vowel heard in “met” and “set”) and “ɤ” symbols on the next tier down indicate the “mid-close” or “half-close” vowels as produced through non-rounded lips and the “ɛ” and “ʌ” symbols indicate the “mid-open” or “half-open” vowels as produced through non-rounded lips. The “ə” or “schwa” symbol (the vowel heard in “father”) is the mid-central vowel and is considered to be the most neutral position that the tongue can achieve.²⁵

It is important to note that this study will be concerned with the different vowels as produced through a change in tongue position and shape *only* and will not include lip-rounding. This is due to the fact that, with the exception of occasional artistic and technical nuances in highly refined flute playing, the flute embouchure will remain consistent for traditional tone production,

²⁵Crystal, *The Cambridge Encyclopedia of the English Language*, 238.

even as the tongue position is manipulated, and will not conform to the usual lip-rounding that would be found in normal speech patterns.

It is important to note that the symbols in this diagram are those that Daniel Jones created and have been included in this discussion to explain the Cardinal Vowel Diagram and understand the different vowel positions within this system. However, this study will be utilizing vowel symbols created by the International Phonetic Association, which are discussed in the following section.

The International Phonetic Alphabet

The International Phonetic Association (IPA) was created in 1886 in Paris by a group of language instructors interested in promoting and popularizing phonetic theory.²⁶ This same year, Danish linguist Otto Jespersen wrote to the association's president, Paul Passy, sharing the idea of creating a phonetic language that could adequately depict all the complex sounds of the world's languages through one standardized, written methodology. The idea was supported by the organization and two years later, in August of 1888, the first International Phonetic Alphabet had been created.²⁷

The International Phonetic Alphabet was created on the following principles:

- I) Each individual sound was to be given its own unique letter/ written indication.
- II) When two sounds were deemed similar enough that there were no alternatives for either in any language, even if the sounds were not truly identical, they would be indicated by the same letter/ written indication.
- III) All non-Roman letter used in the International Phonetic Alphabet were designed to “harmonise well” with the Roman letters utilized in the written designations.
- IV) Diacritical marks, or marks added to a letter to indicate phonetic value or stress, were to be used in the written designation of the IPA only when truly unavoidable.

²⁶International Phonetic Association, “IPA Home,” accessed February 18, 2018, <https://www.internationalphoneticassociation.org>.

²⁷International Phonetic Association. *The Principles of the International Phonetic Association* [London: Department of Phonetics, University College London, 1949], Inside Cover.

- V) The application of the IPA to any one specific language must take into account the theory of phonemes and cardinal sounds, or reference sounds utilized in order to define and categorize the sounds of a language.²⁸

By creating a written designation according to these guidelines, the International Phonetic Association created a universal written language that accounts for and depicts all possible human speech sounds.

Monophthongs Included in This Study

This study will examine the change in resonance spectra in flute tone production as created while producing six different monophthongs. Only monophthongs will be used as a relatively stable tongue position is utilized in the production of traditional flute tone when producing a single pitch at a constant dynamic. The six chosen vowel positions have been selected due to their practical application in flute tone production and their ability to create contrasting timbres, with their associated variance in the resonance spectrum of the flute, among them. The written symbols according to the International Phonetic Alphabet for these six monophthongs are as follows:

- [i] (as heard in “sheep” and “me”)
- [ɪ] (as heard in “mit” and “him”)
- [ə] (the Schwa position as heard in “father” and “comma”)
- [ʊ] (as heard in “put” and “foot”)
- [u] (as heard in “goose” and “soup”)
- [ɔ] (as heard in “thought” and “brought”)²⁹

The remaining two monophthongs have not been included in this study as their physical locations in the oral cavity are only slightly different than the two monophthongs [ɪ] and [ə]. They include:

- [e] (as heard in “bet” and “met”)
- [æ] (as hard in “cat” and “mat”)

²⁸International Phonetic Association. *The Principles of the International Phonetic Association*, 1-2.

²⁹International Phonetic Association, “Full IPA Chart,” accessed February 22, 2018, <https://www.internationalphoneticassociation.org>.

The position of the monophthongs that will be studied, according to the Cardinal Vowel System, is pictured on the following pages. For each diagram, the black dot serves as a visual representation of the vowel's RP Position while the red arrows depict the direction the tongue would move to create each sound in the context of a diphthong. The RP Position, or Received Pronunciation Position, is a term coined by Daniel Jones that indicates the precise position of the vowel on the Cardinal Vowel diagram as pronounced in the “prestige” accent of South-East England.³⁰ For the purposes of this study, is sufficient to utilize these positions as indicated on the Cardinal Vowel Diagram as a frame of reference for understanding their relative position to each other.

Figure 1.3: Location of [i] (Used with permission)

The front of the tongue is placed high to a nearly-closed position, the tongue is firm, the sides of the tongue make firm contact with the upper molars³¹

³⁰Crystal, *The Cambridge Encyclopedia of the English Language*, 365.

³¹Crystal, *The Cambridge Encyclopedia of the English Language*, 240.

Figure 1.4: Location of [ɪ] (Used with permission)

The central area of the tongue placed slightly above the half-closed position, the tongue is somewhat relaxed, the sides of tongue make slight contact with upper molars³²

Figure 1.5: Location of [ə] (Used with permission)

The central area of the tongue is placed between the half-open and half-closed positions, the sides of the tongue make no significant contact with the molars³³

³²Crystal, *The Cambridge Encyclopedia of the English Language*, 240.

³³Crystal, *The Cambridge Encyclopedia of the English Language*, 241.

Figure 1.6: Location of [ʊ] (Used with permission)

The central-back area of the tongue is placed slightly above half-close position, the tongue is somewhat relaxed, the sides of the tongue make no significant contact with the molars³⁴

Figure 1.7: Location of [u] (Used with permission)

The back of the tongue is placed high to a nearly-closed position, the tongue is firm, the sides of the tongue make no significant contact with the molars³⁵

³⁴Crystal, *The Cambridge Encyclopedia of the English Language*, 240.

³⁵Crystal, *The Cambridge Encyclopedia of the English Language*, 240.

Figure 1.8: Location of [ɔ] (Used with permission)

The back of the tongue is placed between half-close and half-open positions, the sides of the tongue make no significant contact with the molars³⁶

³⁶Crystal, *The Cambridge Encyclopedia of the English Language*, 240.

Chapter II: Formant Tuning

Harmonics

A pitch “is composed of a fundamental tone (or frequency of vibration) and a series of higher frequencies called upper harmonics, usually corresponding to a simple mathematical ratio of harmonics, which is 1:2:3:4:5, etc.”³⁷ The fundamental frequency may also be referred to as the pitch and is labeled F0 or H2. Harmonics are another significant element of sound. They are periodic, meaning their frequencies are multiples of the fundamental frequency and sound in regular intervals.³⁸ Overtone, on the other hand, is a broader term for any resonating frequency above the fundamental frequency, whether periodic or non-periodic.³⁹ The distinction here is important because this study will be focusing primarily on the proportional strength of harmonics, both with each other and the fundamental frequency, and their alignment, or lack thereof, with formants. Harmonics make up the overtone series, or the ordering of the higher frequencies that sound with the fundamental. The series of intervals of the overtone series above the fundamental are as follows: H1-H2: one octave, H2-H3: perfect fifth, H3-H4: perfect fourth, H4-H5: major third, H5-H6: minor third, etc.⁴⁰

Figure 2.1 on the following page is a simulation of a source spectrum, or the spectrum of a sound that is not manipulated by any other resonators (such as those that would be found in the human vocal tract).⁴¹ It may be seen that the strength of the harmonics in the tone diminish quite uniformly as the frequency increases, creating a uniform spectral slope. This is significant because

³⁷Encyclopedia Britannica Online, s.v. “Harmonic Structure,” accessed March 8 2018, <https://www.britannica.com/topic/speech-language/Theory-of-voice-production>.

³⁸Rossing, Thomas D. *The Science of Sound* [Massachusetts: Addison-Wesley Publishing Company, 1982], 17, 29.

³⁹Miller, Donald Gray. *Resonance in Singing: Voice Building Through Acoustic Feedback* [New Jersey: Inside View Press, 2008], 114-115.

⁴⁰Encyclopedia Britannica Online, s.v. “Overtones,” accessed April 4, 2018, <https://www.britannica.com/science/sound-physics/Overtones>.

⁴¹Miller, *Resonance in Singing*, 25.

when resonators within the human body are taken into consideration, the slope of the strengths of the different harmonics will no longer be uniform.

Figure 2.1: Resonance Spectrum of a Simulated Source (Source Not Affected by Additional Resonators)⁴² (Used with permission)

Formants

When speaking or singing, the air-filled cavities throughout the human vocal tract, including the pharynx, nasopharynx, nose, and oral cavity, each resonate. The size and length of the vocal tract and the shape of each cavity affects the resonance spectrum of a given frequency, as the different resonances of the cavities can either strengthen or dampen the fundamental frequency and each specific harmonic, including the fundamental frequency, F0. Manipulation of any of the cavities while exhaling (whispering) will also affect the resonance spectrum of the sound

⁴²Miller, *Resonance in Singing*, 25.

similarly, though in this case, there is no vibrating source (vocal folds). The peaks in the sound that are reinforced due to these resonance properties are known as formants. Formants might or might not align with the harmonics of the sound.⁴³ This is significant because while it is understood that changing the size and shape of the oral cavity adjusts the resonance spectrum of a sound, such changes in the oral cavity made while sound is being produced through the flute has not previously been studied. Specifically, this project explores the manner in which the resonant features of a flutist's vocal tract—its formants—affects the frequency spectrum of the sound of the flute and also explores the possibility of using such information to affect how the flute's resulting sound blends with other instruments.

Vowel Formants

If the size and shape of the oral cavity is manipulated, the qualities of its resonance, and therefore the resonance spectrum of the sound produced, is altered. As a result, it is possible to define different monophthongs, or vowel positions, by the strength of their respective formants. Vowels are specifically recognized and categorized by the lowest two formants of the sound, referred to as F1 and F2. Though there are many more formants in a given tone than these, the first two formants are the most audible and therefore the most significant in determining the quality of the resonance of a sound. Formants 1 and 2 the strongest two harmonics in the sound produced, and they may be stronger or weaker than the fundamental frequency itself, with F1 being the most dominant harmonic and F2 being the second-most dominant harmonic.⁴⁴

Figure 2.2 on the following page shows the resonance spectrum for the vowel [i]. The first formant (F1) is a peak of energy in the sound created by the resonance that results from the shape of the pharynx and the second and third formants are peaks created by the resonance that results from cavities within the oral cavity as modified by the tongue.⁴⁵ Comparing this figure with Figure 2.1, it may be seen that passing a sound through these additional resonators within the vocal tract

⁴³Appelman, D. Ralph. *The Science of Vocal Pedagogy* [Bloomington: Indiana University Press, 1967], 126.

⁴⁴Miller, *Resonance in Singing*, 24.

⁴⁵Appelman, *The Science of Vocal Pedagogy*, 126.

changes the slope of the resonance spectrum from being one of uniform descent to one of multiple peaks of varying strengths.

Figure 2.2: Resonance Spectrum of Vowel [i]⁴⁶ (Used with permission)

It is worthwhile to note that the formant tendencies of each vowel remain consistent whether a person is whispering, speaking, or singing. Though a woman's fundamental frequency, harmonics, and formants when speaking the vowel [i] can be slightly higher than a man's, the respective power of each formant in her sound will remain proportionally, relatively, consistent. This makes vowels recognizable by their resonance spectra.⁴⁷

⁴⁶Appelman, *The Science of Vocal Pedagogy*, 126.

⁴⁷Miller, *The Structure of Singing*, 50-51.

Figure 2.3 below shows the resonance spectra, specifically the peaks of the formants, of the following vowels: [i], [I], [e], [æ], [ɔ], [ʊ], and [u]. The figure also provides diagrams of the positions of the vocal organs, based on X-ray images taken during the production of these vowels, and gives a phonological example of each vowel sound as found in the context of a word in the English language.⁴⁸

Figure 2.3: Vowel Formants⁴⁹ (Used with permission)

⁴⁸Miller, *The Structure of Singing*, 55.

⁴⁹Rossing, *The Science of Sound*, 293.

Formant Regions of the Flute

The vibrations of the flute, a cylindrical pipe through which sound is created by air blown across an opening, “form a series of frequencies that includes all the harmonics of the fundamental. The resonance frequencies of the pipe are influenced by the presence of the stream, however.”⁵⁰ Due to their different resonating sources and acoustical properties, every instrument type has a unique resonance spectrum and its own formant regions, or proportionality of the harmonics in the tone, which the ear perceives as the instrument’s distinct timbre or tone color. Additionally, the different registers of the instruments also display different resonance spectra. The formant regions of the flute are most clearly visible in the resonance spectra for the tones as produced through the neutral [ə] vowel position (see Appendix 1).

Formant Tuning

Singers are quite familiar with the concept of formant tuning or vowel modification, which is the deliberate but subtle adjustment of the vowel position when singing in order to change the power of the sung sound or the tone color.⁵¹ “The front vowels (singers often call them ‘high’) have formants that produce brilliance and ‘ring.’ Back vowels (singers frequently term them ‘low’) have lower formants and strike the ear as being less brilliant.”⁵² Minute adjustments in the exact position of the tongue and pharynx enable a singer to adjust the quality of his or her tone. Lifting the tongue will make the tone brighter and more brilliant by reinforcing the upper harmonics, and depressing the tongue will make the tone darker and deeper by reinforcing the lower harmonics in the sound.⁵³ In this study, a brighter sound is defined as having stronger higher harmonics (so that the higher frequencies in the sound are more present) and a darker sound is defined as having more damped higher harmonics (so that the higher frequencies are less present).

⁵⁰Rossing, *The Science of Sound*, 227.

⁵¹Miller, *Resonance in Singing*, 25.

⁵²Miller, *The Structure of Singing*, 150.

⁵³Miller, *The Structure of Singing*, 150-151.

The Singer's Formant

A singer is able to project his or her voice over orchestral accompaniment due to the principles of the singer's formant, a principle that illustrates the significances of formant tuning in musical performance. When singing, the human voice displays a spike in power of the third, fourth, and fifth formants. Additionally, these formants tend to cluster, sounding between 2500 and 3200 Hz for male voices and between 3200 and 4000 Hz for female voices. This region of strengthened harmonics is known as the singer's formant, and it does not affect vowel production, which is defined only by the first and second formants.

The figure below shows the resonance spectra of an orchestra, speech, and the combined sound of an orchestra and a vocalist. The singer's formant assists the singer in projecting his or her sound over the ensemble, as clearly seen in the figure.

Figure 2.4: Resonance Spectra of Speech, Orchestra, and Orchestra/Vocalist⁵⁴ (Used with permission)

⁵⁴Rossing. *The Science of Sound*, 320.

This demonstrates how singers are able to use their understanding of formants and formant tuning to manipulate the oral cavity to find the optimal positions for blending or projecting. Flutists also utilize a variety of vowel positions (specifically monophthongs) when playing to create different qualities of tone color and in order to adjust the strength of their sound. However, it is not yet understood how a flutist changing the shape of his or her oral cavity while playing may change the resonance spectrum of the sound produced or how a flutist may utilize the concept of formant tuning when seeking to blend with other musicians. These are two of the main considerations this study will examine.

Chapter III: The Resonance Spectrum of the C Flute

The Flutists

The flutists in this study were each asked to record four separate pitches (E4, C5, A5, and G6) while producing six different monophthongs. The monophthongs are:

- [i] (as heard in “sheep” and “me”)
- [ɪ] (as heard in “mit” and “him”)
- [ə] (the Schwa position as heard in “father” and “comma”)
- [ʊ] (as heard in “put” and “foot”)
- [u] (as heard in “goose” and “soup”)
- [ɔ] (as heard in “thought” and “brought”)

The pitches included cover all three ranges of the flute and clarinet and the four strings of the violin. They were recorded and analyzed through the software VoceVista, a program designed by vocalist Dr. Donald Gray Miller that records and analyzes sound in live time. This software is able to show the pitch, volume, and resonance spectra of sound.

The flutists included in this study come from different educational and musical backgrounds to ensure that any trends discovered may not be attributed to one particular flute lineage. Alberto Almarza studied with Jeanne Baxtresser and Julius Baker, previously served as the principle flutist of the Philharmonic Orchestra of Santiago, and currently teaches at Carnegie Mellon University. Lindsey Goodman studied with Robert Langevin and Walfrid Kujala, previously served as the principle piccolo of the Chicago Symphony Orchestra, and is currently in her eleventh season as the principle flutist of the West Virginia Symphony Orchestra. Alyssa Schwartz studied with Richard Sherman and Nina Assimakopoulos, previously served as the principle flutist of the West Virginia University Symphony Orchestra, and is currently completing her DMA at West Virginia University.

The Displays of VoceVista

Figure 3.1: The Displays of VoceVista

Figure 3.1 shows the three displays of VoceVista (flutist Alyssa Schwartz playing E4 in the [i] vowel position). The Waveform Envelope (top-left screen) provides the viewer with a “rough indication of the relative sound pressure level” of the given recording. It displays the volume of the overall sound (y-axis) over time (x-axis). One sees, for example, a rather sharp attack of sound in the above sample which is sustained with a slight diminuendo in volume and a very sudden cut-off. The Spectrogram (bottom-left screen) displays the strength of the fundamental frequency (the lowest band) and the respective strength of each harmonic in the sound of the given recording. It displays the frequency (y-axis) of the fundamental frequency and overtones over time (x-axis). This screen also provides information on the respective strengths of the different components of the sound. A brighter, clearer, red-tinted band, (as seen in F0, H2, H3, and H5 in this example) indicates that that frequency is more present in the sound where a dimmer, fuzzier, blue-tinted band (as seen in H8, H9, H10, and H11 in this example) indicates that the frequency is

less present in the sound. The fuzzy, inconsistent band visible prior to the sudden attack of the tone in this recording is the sound of the flutist inhaling prior to playing. The Power Spectrum (right-hand screen) displays the frequency of the sound (across the x-axis, measure in hertz) against the amplitude or power of the sound (across the y-axis, measured in decibels, a unit that indicates the intensity or volume of a sound) at a specific instant in time. The green vertical line running through the Waveform Envelope and the Spectrogram shows where this specific instant occurred in the recording. Each dot on this graph within a vertical column represents 10 decibels. This display provides a snapshot of the power of each part of the sound at any given singular point, by placing the cursor on a specific point in time on either the Waveform Envelope or the Spectrogram.⁵⁵ The program also allows one to measure the amplitude numerically.

The following pages provide a sample of the spectra recorded and a typical analysis that accompanies each.

⁵⁵Miller *Resonance in Singing*, 7-11.

Sample: Resonance Spectra of E4 With [i] Monophthong

Figure 3.2: E4, [i], Alberto Almarza

Figure 3.3: E4, [i], Lindsey Goodman

Figure 3.4: E4, [i], Alyssa Schwartz

With some minor variances among the three analyses, it may be seen by comparing the Power Spectrum of each that the spectral slopes for each decrease in a relatively linear manner with an increase in the frequency of the harmonics. The spectra for Almarza's and Schwartz's recordings reveals that the first formant (F1) falls on the first harmonic (H2). This can be seen most clearly in the Power Spectrum of the recordings, with the highest peak of the graph falling on F0 and the next-highest peak falling on H2. It can also be seen in the Spectrogram of each recording, though it is perhaps more clearly-defined, visually, in the Power Spectrum screens. In Goodman's spectral analysis, H2 and H3 are equal in strength. For all three flutists, F1 and F2 fall on H2 and H3. F1 for all three recordings registers at approximately -5 to -10 dB, or 5-10 decibels below the zero-line at the top of the Power Spectrum screen. H13, H14, and H15 are significantly less present in the sound, averaging -42 to -63 dB among the three flutists.

Analyzing the Spectra

The following noticeable characteristics for each have been measured and identified:

1. Overall shape and characteristics of the spectral slope
2. The location and frequency of the first formant (F1) and second formant (F2)
3. Any strengthened or dampened harmonics
4. Similarities and differences in the results among the three flutists
5. Where appropriate, the strength, in dB, of the various harmonics in relationship to F0 and other harmonics

The overall shape and characteristics of the average spectral slope created by all three flutists are categorized as follows:

- 1) Linear (L): The spectrum displays an overall-linear slope, with the strengths of the harmonics decreasing with an increase in frequency
- 2) Stepped (S): The spectrum displays two or more harmonics of equal or near-equal strength in one or more locations throughout
- 3) Alternating (A): The spectrum displays a pattern of alternating dampened and strengthened harmonics throughout

A spectral slope may include characteristics of more than one of the above categories. For example, Linear-Alternating (LA): The spectrum displays an overall-linear slope with the strengths of the harmonics decreasing with an increase in frequency but also displays a pattern of alternating dampened and strengthened harmonics throughout.

The spectra for each pitch performed with each monophthong by all three flutists, along with a brief summary of salient characteristics, are included in Appendix A. While this information must be included in order to ensure the integrity of the study, the amount of information is too extensive for easy comprehension. The following pages therefore provide a manageable, concise overview of the characteristics of the resonance spectra of each pitch as played with the six different monophthongs included in this study.

Changes in the Resonance Spectra of E4

Table 3.1: Resonance Spectra of E4 on Flute with Various Monophthongs

Monophthong	Spectral Slope	Location and Frequency of F1	Location and Frequency of F2	Strengthened Harmonics	Dampened Harmonics
[i]	L	H2 659.3 Hz	H3 987.8 Hz	H2, H3	H13, H14, H15
[ɪ]	LS	H2 659.3 Hz	H3 987.8 Hz	H2, H3, H5	H9-H15
[ə]	LA	H2 659.3 Hz	H3 987.8 Hz	H2, H3, H5	H8-H15
[ʊ]	LA	H3 987.8 Hz	H2 659.3 Hz	H2, H3, H5	H10-H15
[u]	L	H2 659.3 Hz	Inconclusive	H2, H3, H4	H7-H15
[ɔ]	L	H2 659.3 Hz	H3 987.8 Hz	H2, H3, H5	H6-H15

On average, the higher harmonics (H7 or higher) are 18 dB stronger for this pitch when played with the vowel highest position, [i], when compared with the lowest vowel position, [ɔ]. The first formant tends to fall on the first harmonic and the second formant tends to fall on the second harmonic. Noticeable exceptions to this include [ʊ], where this is reversed, and inconclusive data on the location of F2 for [u] due to inconsistencies in the spectra between the three flutists. The strength of the first formant varies considerably between the highest and lowest positions, averaging -3 dB softer than the fundamental frequency in the highest position and -10 dB softer in the lowest position. The strength of the second formant shows similar changes, averaging -9 dB softer than the fundamental frequency in the highest position and -18 dB softer in the lowest position.

The placement of F1 and F2 as produced while playing the flute for almost all vowel positions on this pitch most closely match the formant regions for the [ɔ] vowel when spoken or sung. The exception here is [ʊ], which is closer to the [a] vowel but does not quite match the spectrum of this vowel when spoken or sung due to the significant damping (only 656 Hz) of F2.

Changes in the Resonance Spectra of C5

Table 3.2: Resonance Spectra of C5 on Flute with Various Monophthongs

Monophthong	Spectral Slope	Location and Frequency of F1	Location and Frequency of F2	Strengthened Harmonics	Dampened Harmonics
[i]	A	H5 2637 Hz	H3 1568 Hz	H3, H5, H7, H9	H2, H4, H6, H8, H10
[ɪ]	SA	Inconclusive	Inconclusive	H7	H6, H8, H9
[ə]	SA	H3 1568 Hz	H2 1047 Hz	H2, H3	H7-H9
[ʊ]	LA	H3 1568 Hz	H2 1047 Hz	H2, H3, H5	Inconclusive
[u]	LS	H3 1568 Hz	H2 1047 Hz	H2, H3, H4	H7, H9
[ɔ]	LS	H3 1568 Hz	H2 1047 Hz	H2, H3, H4	H5-H9

On average, the higher harmonics (H7 or higher) are 9 dB stronger for this pitch when played with the highest position, [i], when compared with the lowest position, [ɔ]. The first formant tends to fall on the second harmonic and the second formant tends to fall on the first harmonic. Noticeable exceptions to this include [i], where the first formant falls on the fourth harmonic and the second formant falls on the second harmonic and [ɪ], which was inconclusive due to inconsistencies between the three flutists. The strength of the first formant averages -14 dB softer than the fundamental frequency in the highest position and -19 dB softer in the lowest position. The strength of the second formant averages -23 dB softer than the fundamental frequency in the highest position and -25 dB softer in the lowest position. It is interesting to note that the spectral slope of

C5 in the [i] position is strongly alternating in its pattern among all three flutists. The even-numbered harmonics average 23 dB stronger than the dampened odd-numbered harmonics.

The frequencies of F1 and F2 for this pitch as played on flute are, for the most part, higher than the frequencies of F1 and F2 as achieved with the human voice. The proportion of the strengths of F1 and F2 on this pitch as played on the flute in the [ə], [ʊ], [u], and [ɔ] positions most closely match the formant regions of the [o] and [ɔ] vowels when spoken or sung. However, the weakness of F2 in comparison with F1 is such that the formant regions of these vowel positions on the flute do not quite align with any of the formant regions of vowels produced with the human voice. This is also true for the formant regions created in the [i] position on this pitch.

Changes in the Resonance Spectra of A5

Table 3.3: Resonance Spectra of A5 on Flute with Various Monophthongs

Monophthong	Spectral Slope	Location and Frequency of F1	Location and Frequency of F2	Strengthened Harmonics	Dampened Harmonics
[i]	A	H3 2637 Hz	H2 1760 Hz	H2, H3	H4, H5
[ɪ]	A	H3 2637 Hz	H2 1760 Hz	H2, H3	H4, H5
[ə]	A	H3 2637 Hz	H2 1760 Hz	H2, H3	H4, H5
[ʊ]	LA	H2 1760 Hz	Inconclusive	H2, H3	H4, H5
[u]	LA	Inconclusive	Inconclusive	H2, H3	H4, H5
[ɔ]	LA	H2 1760 Hz	H3 2637 Hz	H2, H3	H4, H5

On average, the higher harmonics (H4 and H5) are equal in strength for this pitch when played with the highest position, [i], when compared with the lowest position, [ɔ]. However, there is a noticeable change the proportionality of the strengthened harmonics (H2 and H3) and the dampened harmonics (H4 and H5). In the highest position, strengthened harmonics average 24 dB louder than the dampened harmonics, and in the lowest position, the strengthened harmonics average 31 dB louder. The first formant tends to fall on the second harmonic and the second formant tends to fall on the first harmonic for the higher positions. However, this changes for the lower positions, with the first formant falling on the first harmonic and the second formant falling on the second harmonic for [ɔ]. Additionally, the higher positions yield spectral slopes of an alternating nature and the lower positions yield spectral slopes that are both alternating and somewhat more linear.

The frequencies of F1 and F2 for this pitch as played on flute are higher than the frequencies of F1 and F2 as achieved with the human voice. The proportion of the strengths of F1 and F2 on this pitch as played on the flute in the [i], [ɪ], and [ə] positions most closely match the formant regions of the [a] vowel when spoken or sung. For these vowel positions, the weakness of F2 in comparison with F1 is such that the formant regions of these vowel positions on the flute do not quite align with any of the formant regions of vowels produced with the human voice. However, it is interesting to note that the proportion of the formants regions in the [ə] position for this pitch as played on the flute match the formant regions of the [u] vowel precisely when spoken or sung.

Changes in the Resonance Spectra of G6

Table 3.4: Resonance Spectra of G6 on Flute with Various Monophthongs

Monophthong	Spectral Slope	Location and Frequency of F1	Location and Frequency of F2	Strengthened Harmonics	Dampened Harmonics
[i]	A	H3 4699 Hz	H2 3136 Hz	H3	H2
[ɪ]	A	H3 4699 Hz	H2 3136 Hz	H3	H2
[ə]	LA	H2 3136 Hz	H3 4699 Hz	H2	H3
[ʊ]	A	H3 4699 Hz	Inconclusive	H3	H2
[u]	A	H3 4699 Hz	H2 3136 Hz	H3	H2
[ɔ]	L	Inconclusive	Inconclusive	Inconclusive	Inconclusive

On average, H3 is 17 dB stronger for this pitch when played with the highest position, [i], when compared with the lowest position, [ɔ]. There is also a noticeable change the proportionality of the strengthened harmonic compared with the weaker harmonic. In the highest position, the strengthened harmonic averages 35 dB stronger than the damped harmonic while in the lowest position, the contrast is less drastic, with the strengthened harmonics averaging 22 dB stronger. For most of the positions on this pitch, the first formant tends to fall on the second harmonic and the second formant tends to fall on the first harmonic. Noticeable exceptions to this include [ə], where this is reversed, and [ɔ], which is inconclusive due to inconsistencies between the three flutists. Overall, all positions yield spectral slopes of an alternating nature.

The frequencies of F1 and F2 for this pitch as played on flute are higher than the frequencies of F1 and F2 as achieved with the human voice. The proportion of the strengths of F1 and F2 on this pitch as played on the flute in all the vowel positions studied do not closely align with the formant regions of any vowels when spoken or sung. However, it is interesting to note that the formant regions of the [ə] position are somewhat closer in alignment to the formant regions of the [i] vowel.

As seen in the findings above, monophthongs change the resonance spectra of the flute in ways that can be measured and described and can be compared with the spectra of the human voice, especially vocal monophthongs.

Chapter IV: The Resonance Spectrum of the Violin and Clarinet

The Musicians

A group of three violinists and a clarinetist were asked to record the four pitches E4, C5, A5, and G6 while producing a generic tone quality. Three violinists were asked to play simultaneously in order to create a chorus effect. A group of violins and a single clarinet were selected for this study as flutists are sometimes required to blend with these instruments in performance settings, particularly orchestral.

The violinists include Sean Elliott, Allison L'Ecuyer, and Amanda Frampton, all students at West Virginia University with Dr. Mikylah McTeer. The clarinetist in this study is Dr. John Weigand, a member of the faculty at West Virginia University who also performs regularly with the Baltimore Symphony Orchestra.

Analyzing the Spectra

The following noticeable characteristics for each have been measured and identified:

1. Overall shape and characteristics of the spectral slope
2. The location and frequency of the first formant (F1) and second formant (F2)
3. Any strengthened or dampened harmonics
4. Where appropriate, the strength, in dB, of the various harmonics in relationship to F0 and other harmonics
5. Any similarities and differences as compared with the average spectral analyses of the flutists

The spectra for each pitch performed on both instruments along with a brief summary of salient characteristics are included in Appendix B. The following pages provide an overview of the characteristics of the resonance spectra of each pitch as played on each instrument as well as audio files, taken from VoceVista, that combine the flutists' recordings with those of the violin and clarinet. The flutists' sounds were chosen at random to ensure the data was not slanted in favor of any single musician.

Resonance Spectra of Three Violins

Table 4.1: Resonance Spectra of Three Violins

Pitch	Spectral Slope	Location and Frequency of F1	Location and Frequency of F2	Strengthened Harmonics	Dampened Harmonics
E4	S	H5 1661 Hz	H3 987.7 Hz	H3, H4, H5, H7, H10	H2, H6, H8, H9, H11-H15
C5	L	H3 1568 Hz	H2 1047 Hz	H2, H3, H7	H8, H9
A5	LA	H2 1760 Hz	H4 3520 Hz	H2, H4	H3, H5
G6	L	H2 3136 Hz	H3 4699 Hz	H2	H3

The resonance spectrum of violinists on E4 most closely matches the resonance spectrum of flutists in the [ʊ] position. Both produce a stepped spectral slope, a boost in strength of H5, a dampening of H8, and dampened higher harmonics (H11-H14). A neutral-low vowel position for the flutist, such as [ə] or [ʊ] will yield more homogeneity when blending with violinists in this register. The following audio file, consisting of the audio file of flutist Lindsey Goodman performing E4 with the [ʊ] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.1: Lindsey Goodman, \[ʊ\], and Violinists, E4](#)

Alternately, a higher vowel position, such as [i] or [ɪ], both of which produce stronger higher harmonics, would help brighten a flutist's sound, making the flute tone more dominant in the balance of the blend. The following audio file, consisting of the audio file of the same flutist

performing E4 with the [i] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.2: Lindsey Goodman, \[i\], and Violinists, E4](#)

The resonance spectrum of violinists on C5 most closely matches the resonance spectrum of flutists in the [ə] position. Both produce relatively linear spectral slopes and display F1/H3 and F2/H2 and a dampening of H8 and H9. The spectra of the [ʊ] position for flutists also matches that of the violinists quite closely. The following audio file, consisting of the audio file of flutist Alberto Almarza performing C5 with the [ə] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.3: Alberto Almarza, \[ə\], and Violinists, C5](#)

A higher vowel position, such as [i] or [ɪ], both of which produce stronger higher harmonics, would help brighten a flutist's sound, making the flute tone more dominant in the balance of the blend. The following audio file, consisting of the audio file of the same flutist performing E4 with the [ɪ] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.4: Alberto Almarza, \[ɪ\], and Violinists, C5](#)

For A5, the spectra of the violinists and flutists most closely align when the flutists produce tone in the [ʊ], [u], and [ɔ] positions, with F1 falling on H2 and linear-alternating spectral slopes. F2 falls on H4 for the violinists' sound, but the placement of F2 is less consistent in the flute sound. The following audio file, consisting of the audio file of flutist Alyssa Schwartz performing A5 with the [ɔ] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.5: Alyssa Schwartz, \[ɔ\], and Violinists, A5](#)

A higher vowel position would help brighten a flutist's sound, making the flute tone more dominant in the balance of the blend. The following audio file, consisting of the audio file of the same flutist performing A5 with the [i] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.6: Alyssa Schwartz, \[i\], and Violinists, A5](#)

The resonance spectra of violinists on G6 most closely matches the spectrum of flutists in the [ə] position. Both produce linear spectral slopes with significant strengthening of H2 (F1). The following audio file, consisting of the audio file of flutist Lindsey Goodman performing G6 with the [ə] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.7: Lindsey Goodman, \[ə\], and Violinists, G6](#)

A lower vowel position would help darken a flutist's sound, making the flute tone less dominant in the balance of the blend. The following audio file, consisting of the audio file of the same flutist performing G6 with the [ɔ] position and the violinists performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.8: Lindsey Goodman, \[ɔ\], and Violinists, G6](#)

This information will be applied to orchestral passages in Chapter V.

Resonance Spectra of the Clarinet

Table 4.2: Resonance Spectra of the Clarinet

Pitch	Spectral Slope	Location and Frequency of F1	Location and Frequency of F2	Strengthened Harmonics	Dampened Harmonics
E4	LA	H3 987.8 Hz	H9 2960 Hz	H3, H5, H9	H2, H4, H6, H12-H15
C5	SA	H3 1568 Hz	H4 2093 Hz	H4, H4, H9	H2, H8, H10
A5	A	H2 1760 Hz	H4 3520 Hz	H3, H5, H7, H9	H2, H4, H6, H8, H10
G6	A	H3 4699 Hz	H2 3136 Hz	H3	H2

The resonance spectrum of the clarinetist on E4 most closely matches the resonance spectrum of the flutists in the [ʊ] position, with F1 falling on H3 for both and noticeable dampening of H12-H15. Both also display a spike in power of H5. However, the spectral slope of flutists in the [ə] position is also quite similar to that of the clarinet, though the placement of F1 falls on H2 for the flutists. A neutral or neutral-low vowel position for the flutists will yield more homogeneity when blending with clarinet in this register. The following audio file, consisting of the audio file of flutist Alberto Almarza performing E4 with the [ə] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.9: Alberto Almarza, \[ə\], and Clarinetist, E4](#)

A higher vowel position, such as [i] or [ɪ], both of which produce stronger higher harmonics and a stronger F1 and F2, would help brighten a flutist's sound. The following audio file, consisting of

the audio file of the same flutist performing E4 with the [i] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.10: Alberto Almarza, \[i\], and Clarinetist, E4](#)

The resonance spectrum of the clarinetist on C5 most closely matches the resonance spectrum of the flutists in the [ə] position, with F1 falling on H3 and a noticeable plateau in the power of H5-H7 in both spectra. While the placement of F1 and F2 for the flutists was inconclusive when playing in the [i] position, this spectral slope is also quite similar to that of the clarinet. It is reasonable to conclude that a high-neutral or neutral vowel position for the flutists will yield a more homogenous blend with the clarinet in this register. The following audio file, consisting of the audio file of flutist Alyssa Schwartz performing C5 with the [ə] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.11: Alyssa Schwartz, \[ə\], and Clarinetist, C5](#)

A lower vowel position would help darken a flutist's sound, making the flute tone less dominant in the balance of the blend. The following audio file, consisting of the audio file of the same flutist performing C5 with the [ɔ] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.12: Alyssa Schwartz, \[ɔ\], and Clarinetist, C5](#)

For A5, the spectra of the clarinetist and the flutist most closely align when the flutists produce tone in the [i] and [ɪ] positions. Though the placement of the formants does not align, the spectral slopes in these positions are quite close to that of the clarinet, with the strengths H2 and H3 displaying a proportional dampening in comparison with F0 (averaging -17 dB softer for both instruments). Additionally, the H4 and H5 are more dominant in the flute sound in these two positions than in the lower vowels, more closely matching the strength of these two harmonics in the clarinet sound. It is reasonable to conclude that high and high-neutral vowel positions will yield a more homogenous blend between flute and clarinet in this register. The following audio file,

consisting of the audio file of flutist Lindsey Goodman performing A5 with the [i] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.13: Lindsey Goodman, \[i\], and Clarinetist, A5](#)

A lower vowel position would help darken a flutist's sound, making the flute tone less dominant in the balance of the blend. The following audio file, consisting of the audio file of the same flutist performing A5 with the [ʊ] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.14: Lindsey Goodman, \[ʊ\], and Clarinetist, A5](#)

The resonance spectra of the clarinetist on G6 most closely matches that of the flutists in the [u] position, with F1 falling on H3 and F2 falling on H2 for both and the strengths of each formants in relationship to the strength of the fundamental aligning quite closely (only varying by approximately -8 dB). It is reasonable to conclude that lower vowel positions will yield a more homogenous blend between flute and clarinet in this register. The following audio file, consisting of the audio file of flutist Alberto Almarza performing G6 with the [u] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.15: Alberto Almarza, \[u\], and Clarinetist, G6](#)

A higher vowel position, such as [i] or [ɪ], both of which produce stronger higher harmonics and a stronger F1 and F2, would help brighten a flutist's sound. The following audio file, consisting of the audio file of the same flutist performing G64 with the [ɪ] position and the clarinetist performing the same pitch as extracted from VoceVista, demonstrates this:

[Audio File 4.16: Alberto Almarza, \[ɪ\], and Clarinetist, G6](#)

This chapter has demonstrated that blend can be modified through the use of monophthongs that can be represented through the IPA and described using standard vocabulary associated with phonetics. This information will be applied to orchestral passages in Chapter VI.

Chapter V: Blending: C Flute and Violin

This section will discuss five orchestral excerpts in which the flutist is required to blend with the violin section. Based on the resonance spectra of both instruments in different registers, and for the flutists with different vowel positions, suggestions for vowel positions that will yield a more or less homogenous blend in each excerpt will be provided.

Orchestral Suite No. 2 in B Minor, Movement V, “Polonaise,” by Johann Sebastian Bach

This orchestral suite, composed in 1738-39, consists of seven movements and is scored for flute, strings, and continuo. The fifth movement, Polonaise and Double, opens with the main theme being presented in the flute and violins, doubled at the octave, as seen in the figure below.

Polonaise. *da Capo.*

Moderato e staccato.

lentement

The musical score for the Polonaise from Orchestral Suite No. 2 by J.S. Bach is presented in two systems. The first system includes staves for Flute, Violin, Viola, and Cello/Double Bass. The second system includes staves for Flute, Violin, Viola, and Cello/Double Bass. The score is marked 'Moderato e staccato' and 'da Capo'. The first system is marked 'lentement' and the second system is marked 'piano' and 'forte'. The score includes various musical notations such as notes, rests, and dynamics.

Figure 5.1: Polonaise from Orchestral Suite No. 2 by J. S. Bach

The flute line is written at the top of the middle register/ bottom of the lower register of the instrument, while the violin line, one octave lower, sounds on the middle-low register of the instrument. The resonance spectra of the flutists in the lower vowel positions [ʊ] and [ɔ] in this register most closely matches the spectrum of the violinists in their lower register in this excerpt. F1 falls on H2 for the both the violinists and the flutists in both positions. Though the placement of the formants for the flutists playing in the [u] position was inconclusive due to inconsistencies among the three flutists, the spectral slope for this position also displays some similarities to that of the violins, with a noticeable strengthening of H4 and dampening of H5.

When performing this excerpt, the flutist will achieve a more homogenous blend with the violinists if performing with a lower vowel position. Performing with a higher vowel position, which results in F1 falling on a higher harmonic (H3 as opposed to H2) and an increase in strength of H4 and H5, will yield a brighter sound on the part of the flutist, which will help further distinguish the flute tone from that of the violins.

Symphony No. 92 in G Major, Movement II, by Joseph Haydn

This symphony, composed in 1789, consists of four movements and is scored for flute, oboe, bassoon, horn, trumpets, timpani, and strings. The second movement opens with a melody presented in the violins (seventh staff) which is then repeated with octave doubling by the flute (first staff) eight measures later, as seen in the figure on the follow page.

The image displays two systems of a musical score for Joseph Haydn's Symphony No. 92, Movement II. The notation is arranged in two systems, each containing multiple staves for different instruments. The key signature is one sharp (F#), and the time signature is 3/4. The first system begins with a *cantabile* marking and a *p* (piano) dynamic. The second system features a *p 5654* marking. The score includes various musical notations such as notes, rests, and dynamic markings like *p*, *cantabile*, and *p 5654*.

Figure 5.2: Excerpt from Movement II, Symphony No, 92 by Joseph Haydn

The flute line is written predominantly in the middle register of the instrument with two brief peaks just reaching into the third register, while the violin line, one octave lower, sounds in the middle-lower range of the instrument. The resonance spectra of the flutists in the high [i] position in this register most closely matches the spectrum of the violinists in their lower register in this excerpt. F1 falls on H3 and F2 falls on H2 for both instruments, and both display noticeable dampening of H4.

When performing this excerpt, the flutist will achieve a more homogenous blend with the violinists if performing with a higher vowel position. Performing with a more neutral or lower vowel position, which results in F1 falling on a lower harmonic (H2) and a decrease in strength of higher harmonics will yield a darker sound on the part of the flutist, which will serve to highlight the presence of the violin sound in the blend.

Symphony No. 3 in Eb Major, “Eroica,” Movement IV, by Ludwig van Beethoven

This symphony, composed in 1803-1804, consists of four movements and is scored for full orchestra. There is an exposed third-register flute solo beginning in measure 177 in the fourth movement, which is doubled by the violins at the octave for the first eight measures (as seen in the figure on the following page).

Fl. *ff* *p*

Ob. *ff* *p*

Cl. *ff* *p*

Fg. *ff* *p*

Vl. *ff* *p*

Vla. *ff* *p*

Vc. Cb. *ff* *p* pizz.

32

Fl. *cresc.* *f* *p*

Ob. *p*

Vl. *cresc.* *sf* *p*

Vla. *cresc.* *sf* *p*

Vc. Cb. *cresc.* *p*

Figure 5.3: Flute Solo from Movement IV, Symphony No. 3 by Ludwig van Beethoven

The flute line is scored in the high register while the violin, again one octave lower, is scored in the middle register in this excerpt. The resonance spectra of the flutists in the neutral-lower vowel positions in this register most closely matches that of the violins in their register in this excerpt. The neutral [ə] position yields the lowest F1 (falling on H2) for the flutists, more closely aligning their first formant with that of the violins (which also falls on H2). However, the spectral slopes for the flutists in the [ʊ], [u], and [ɔ] positions more closely match the overall spectral slope of the violinists in this register, displaying slopes with alternating characteristics.

When performing this excerpt, the flutist will achieve a more homogenous blend with the violinists if performing with a neutral or lower vowel position. Performing with a higher vowel position, which results in an increase in strength of the higher harmonics, will yield a brighter sound on the part of the flutist, which will help further distinguish the flute tone from that of the violins.

Symphony No. 5 in D Minor, Op. 47, Movement I, by Dmitri Shostakovich

This symphony, composed in 1937, consists of four movements and is scored for full orchestra. There is an exposed flute and violin line in unison (in the third register of the flute) that begins at Rehearsal 4, as seen in the figure on the following pages.

3

Fl. I, II

V-ni I

V-ni II

V-le

V-c.

C-b.

p

pp

f

a2

4

Fl. I, II

V-ni I

V-ni II

V-le

V-c.

C-b.

p

cresc.

f

a2

5

Fl. I, II

V-ni I

V-ni II

V-le

V-c.

C-b.

dim.

p

cresc.

a2

Figure 5.4: Excerpt from Movement I, Symphony No. 5 in D Minor by Dmitri Shostakovich

The resonance spectra of the flutists in the neutral [ə] position most closely matches that of the violins in this register. Performing with a higher vowel position will yield a brighter sound on the part of the flutist, while performing with a lower position, which dampens the formants and higher harmonics, will result in a darkening of the flute tone.

Four Seas Interludes, Movement I, “Dawn, from Peter Grimes, op. 33a, by Benjamin Britten

The opera *Peter Grimes* by Benjamin Britten was premiered in 1945. The composer later extracted four interludes to be performed as a stand-alone symphonic piece.⁵⁶ The majority of the melodic material in the first movement, “Dawn,” is presented in unison by the flutes and violins. An excerpt has not been included because the score is under copyright.

⁵⁶May, Thomas. *The Kennedy Center*, s.v. “Four Seas Interludes from Peter Grimes, Op. 33a,” accessed April 4, 2018, <http://www.kennedy-center.org/artist/composition/3178>.

The range of this material for the flutists and violinists is quite broad, spanning from a sustained unison trill on G#4 (beginning in the first measure of page 7 in the score) to the climax, a unison C7 (as seen in the third measure of page 6 in the score). The majority of this excerpt is written in the third register for the flutist, centering predominantly around E6.

The resonance spectra of the flutists in the neutral [ə] position most closely matches that of the violins in the higher register. Playing in a neutral position will yield a more homogenous blend with the violinists for the majority of this excerpt. In the middle register material, a slightly lower vowel position on the part of the flutists will yield a higher level of blend with the violinists (a vowel placed somewhere in the range [ə]-[u]). Middle register material in this excerpt can be seen beginning in the last measure of page 1 continuing through the first two measures of page 2, the last two measures of page 6, and the last measure of the movement in the score. In the lower register of the material, as seen on page 7 in the score, a slightly lower vowel position on the part of the flutists will yield a higher level of blend (again, a vowel in the [ə]-[u] range). In any range, playing with a higher vowel position will brighten the flutist's sound while playing with a lower position will darken the flutist's sound.

Chapter VI: Blending: C Flute and Clarinet

This section will provide three orchestral excerpts in which the flutist is required to blend with the clarinetist. Based on the resonance spectra of both instruments in different registers, and for the flutists with different vowel positions, suggestions for vowel positions that will yield a more or less homogenous blend in each excerpt will be provided.

Tarantelle for Flute and Clarinet, Op. 6, by Camille Saint-Saëns

Composed in 1857, this tarantella is written for solo flute and clarinet and orchestra. Both solo instruments share the melody throughout the majority of the piece, often sounding in thirds or sixths when performing simultaneously. The notable exception, and the passage under consideration here, begins shortly before Rehearsal E, as seen in the figure on the following pages. The solo flute line is the eighth staff and the solo clarinet line is the ninth.

This page of a musical score, numbered 56, features a piano and orchestra arrangement. The score is written in G major (one sharp) and 4/4 time. It consists of 16 measures, divided into two systems of eight measures each. The piano part is written on a grand staff (treble and bass clefs). The orchestral part includes staves for strings (violin I, violin II, viola, cello, and double bass) and woodwinds (flute, oboe, and bassoon). The piano part begins with a first ending bracket over measures 1-4, marked *dim.* (diminuendo). The orchestral part enters in measure 5 with a *pp* (pianissimo) dynamic. The piano part continues with a second ending bracket over measures 9-12, also marked *dim.*. The orchestral part continues with *pp* dynamics. The score concludes with a final measure in measure 16, marked *pp*.

307

E

The musical score is for a large ensemble, including Flute, Clarinet, and various strings. It features complex rhythmic patterns, dynamic markings (cresc., dim., pp), and articulation (Alto div.). The key signature is D major (two sharps). The score is divided into three systems. The first system has 8 measures. The second system has 8 measures. The third system has 8 measures. The score ends with a double bar line and a final 'E' marking.

E

E

E

E

Figure 6.1: Excerpt from Tarantelle for Flute and Clarinet by Camille Saint-Saëns

The flute line spans from the top of the middle register to the lower portion of the upper register and the clarinet, scored one octave lower, spans from the top of the chalumeau (low register) through the clarion (middle register). The resonance spectra of the flutists in the lower vowel positions [ʊ], [u], and [ɔ] in this register most closely match that of the clarinet in its register in this excerpt. In both the [ʊ] and [ɔ] positions, F1 falls on H2, which is also the case in the spectrum of the clarinet. While the placement of the first formant is inconclusive in the [u] position for the flutists due to inconsistencies among the three players, the spectral slopes for these vowel positions are the most similar to that of the clarinet due to their more linear quality.

It is reasonable to conclude that a lower vowel position for the flutist will yield more homogeneity when blending with the clarinet in this excerpt. Furthermore, it stands to reason that a higher vowel position, such as [i] or [ɪ], both of which produce stronger higher harmonics and the placement of F1 on a higher harmonic (H3), would result in a brighter sound for the flutist.

Symphony No. 2 in D Major, Op. 73, Movement IV, by Johannes Brahms

This symphony, composed in 1877, consists of four movements and is scored for two flutes, two oboes, two clarinets, two bassoons, four horns, two trumpets, three trombones, tuba, strings, and timpani. Solo flute, clarinet, and bassoon and strings present a melodic line in octaves beginning in measure 170 in the fourth movement which gives way to a melodic line presented in octaves between the flute and clarinet beginning in measure 177, as seen in the figure on the following pages.

168

Fl. 1, 2

Cl. 1, 2

Bsn. 1, 2

Vln. 1

Vln. 2

Vla.

Vc.

Cb.

p

1 solo

legg.

175

Fl. 1, 2

Cl. 1, 2

Bsn. 1, 2

Vln. 1

Vln. 2

Vla.

Vc.

Capriccio Espagnol, Op. 34, Movement IV “Scena e canto gitano” by Nikolai Rimsky-Korsakov

Composed in 1887, this orchestral suite consists of five movements and is scored for full orchestra. The fourth movement, “Scena e canto gitano,” presents an exposed solo line in the first flute and clarinet, doubled in octaves, following the opening horn/ trombone fanfare and violin cadenza, as seen in the figure below.

The image shows a page from a musical score for Nikolai Rimsky-Korsakov's *Capriccio Espagnol*. The page is numbered 62 in the top right corner. The score is for a Flute/Clarinet Solo, as indicated by the title 'Figure 6.3: Flute/ Clarinet Solo from Capriccio Espagnol by Nikolai Rimsky-Korsakov'. The score includes staves for Flute (Fl.), Clarinet (Cl. (A)), Timpani (Timp.), Trombone (T.), Percussion (Pti.), Violin (Vi.), Viola (Vla.), Violoncello (Vcl.), and Contrabass (Cb.). The Flute and Clarinet parts are the primary focus, with the Flute line spanning from the top of the middle register to the lower portion of the upper register. The Clarinet line spans from the top of the chalumeau through the clarion. The Violin and Viola parts are marked 'arco' and 'pizz.' (pizzicato). The Timpani part is marked 'fpp' (fortissimo). The score is labeled 'Cadenza III brillante'.

Figure 6.3: Flute/ Clarinet Solo from Capriccio Espagnol by Nikolai Rimsky-Korsakov

The flute line spans from the top of the middle register to the lower portion of the upper register and the clarinet, scored one octave lower, spans from the top of the chalumeau through the clarion. The resonance spectra of the flutists in the lower vowel positions [ʊ], [u], and [ɔ] in this register most closely match that of the clarinet in its register in this excerpt. It is reasonable to conclude that a lower vowel position for the flutist will yield more homogeneity when blending with the clarinet in this excerpt while a higher vowel position would produce a brighter sound for the flutist.

These orchestral excerpts are each in the same register for both instruments.

Conclusion

Changing the position of the tongue, and therefore the shape of the oral cavity, while playing the flute affects the resonance spectrum of the tone of the instrument, which changes the quality of the tone produced as well as the flute's ability to blend with other instruments. Certain vowel positions yield more or less homogenous blend with different instruments in their different registers.

When the placement of the first and second formants, the strength of the formants in relationship to the fundamental frequency and each other, and the overall spectral slopes more closely align between the sounds produced, a higher level of blend between the two instruments is achieved. When the formants or higher harmonics of one instrument are more present in the sound, the tone of that instrument tends to sound brighter by comparison. When the formants or higher harmonics of one instrument are less present in the sound, the tone tends to sound darker by comparison.

The table on the following page provides an outline of vowel positions for the flutist that will yield a more homogenous blend when playing in unison or octaves with the violin and clarinet in different registers.

Table Key

CF	[i]	Close, Front
NCF	[ɪ]	Near-Close, Near-Front
MC	[ə]	Mid, Central
NCB	[ʊ]	Near-Close, Near-Back
CB	[u]	Close, Back
OMB	[ɔ]	Open-Mid, Back

The designations of “front,” “near-front,” “central,” “near-back,” and “back” refer to the position of the tongue front-to-back in the oral cavity, with “front” indicating the tongue is pushed forward toward the teeth and “back” indicating the tongue is pulled toward the back of the mouth. The designations of “close,” “near-close,” “close-mid,” “mid,” “open-mid,” “near-open,” and “open” refer to the height of the tongue within the oral cavity, with “closed” indicating the tongue is as

high in the mouth as it can be while still creating a vowel and “open” indicating the tongue is low in the mouth and dropped. These labels are taken from the Cardinal Vowel System.⁵⁷

Table 7.1: Vowel Placement for Flutists for Blend with Violin and Clarinet

	Flute, Low Register (B3-B4)	Flute, Middle Register (C5-B5)	Flute, High Register (C6-B6)
Violin Low Register, G String	MC-CB [ə], [ʊ], [u]	CF-NCF [i], [ɪ]	NCB-OMB [ʊ], [u], [ɔ]
Violin Middle Register, D String	MC [ə]	MC [ə]	NCB-OMB [ʊ], [u], [ɔ]
Violin Middle Register, A String	NCF-MC [ɪ], [ə]	NCB-OMB [ʊ], [u], [ɔ]	MC-CB [ə], [ʊ], [u]
Violin High Register, E String	CF-NCF [i], [ɪ]	CF-MC [i], [ɪ], [ə]	MC [ə]
Clarinet Chalumeau (E3-Bb4)	MC-CB [ə], [ʊ], [u]	NCB-OMB [ʊ], [u], [ɔ]	CB-OMB [ʊ], [u]
Clarinet Clarion (B4-C6)	MC-NCB [ə], [ʊ]	CF-MC [i], [ɪ], [ə]	MC [ə]
Clarinet Altissimo (C36-C7)	NCF-MC [ɪ], [ə]	NCF-MC [ɪ], [ə]	CB-OMB [ʊ], [u]

It is necessary to understand that the size and shape of the oral cavity is only one consideration out of several important factors when it comes to blend when playing with other instruments, intonation and dynamic being chief among these. The above suggestions are given with the understanding that the dynamic level of each instrument is equal and that the pitches are sounding in unisons or octaves, only.

It is also important to understand that deliberately utilizing different vowels will simply change the nature of the blend between the two instruments. As long as the intonation between the

⁵⁷Crystal, David. *The Cambridge Encyclopedia of the English Language*, 240.

two remains consistent, a flutist's deliberate use of a higher, more closed vowel to achieve a brighter tone or a further-back, more open vowel to achieve a darker tone to deliberately shift the balance between the two instruments can be a very affective and desired artistic choice.

These conclusions do not mean to suggest that the above vowel placements are ideal or more correct than others. Rather, this is meant to serve as a guide so that flutists may have a more specific understanding of why and how changing vowel positions produce a higher or lower level of blend when playing with the violin and clarinet. The level of blend, and the correlative choice of vowel position, is influenced by such issues as whether the flute doubles the other instrument for the entire passage, whether tonal contrast seems desired, and whether the flute begins to double mid-phrase. Flutists must also consider how vowel shapes might affect intonation, stability of pitch, and volume.

There are a number of subjects that would be interesting for future study based on this research. It would be useful to measure the shape and position of the flutists' tongues while creating different monophthongs in order to see the accuracy of the vowels they are creating and to note any inconsistencies in the physical creation of these positions. A study of the relationship of the formation of the embouchure with the timbre of the tone produced is another area of interest. It would also be worthwhile to record a flutist and a clarinetist or violinist simultaneously as the flutist produces tone with different vowel positions in order to examine how the resonance spectrum of their composite sound changes.

Recording and analyzing the resonance spectra of other orchestral instruments would also be a valuable area of study. For flutists, who are required quite frequently to play with oboe, it would be interesting to learn which vowel positions would yield a higher or lower level of blend with the oboe throughout the two instruments' different registers. It would also be interesting to record and analyze the spectra of multiple instruments (for example, clarinet and oboe together) to see how different vowel positions for the flutist may change his or her ability to blend with these different combinations. Examining how flutists with different dialects or accents may approach forming vowels differently and how this might also affect the resonance spectrum of their tone might also be of interest, as would be the study of blending with different violin sections, perhaps trained in different schools of technique. Analyzing in detail the changes in the resonance spectra of the flute tone produced with wide vibrato (studying the differences in the peaks and valleys of the vibrato) might also be of value. It would be interesting to record a flute with various

microphones and see how they might color the spectrum and to use other digital programs to see if they might shed any further light on these observations.

This study has demonstrated that a flutist's accurate production of different vowel positions as a means of formant tuning while producing flute tone throughout the different registers of the instrument is a technique of worth.

Appendix 1

Notes Concerning Spectra in this Appendix

- The Waveform Envelope in the spectral reading for some of the recordings show that a wider, more notable vibrato was used while recording this pitch. For example, see Figure A1.7. Several of the flutist's recordings throughout this appendix included pitches created with a more prominent vibrato. However, the change in the amplitude of the vibrato does not affect the timbre or resonance spectrum of the sound.
- A number of the spectra include sound that was recorded and analyzed by VoceVista immediately prior to or after a given pitch in a given vowel position was played. These peripheral sounds may be seen in the Waveform Envelope and the Spectrogram of the spectra. Peripheral sound prior to the recorded pitch, as seen in Figure. A1.1, is a recording of the flutist verbally pronouncing the vowel prior to playing in that vowel position. Peripheral sound immediately after the pitch was played, as seen A1.23, includes the sound of the flutist setting the instrument down. These sounds did not affect the timbre or resonance spectrum of the pitch recorded.
- There are several spectra in which it might appear, when viewing the Waveform Envelope, that the volume of the sound recorded overwhelmed the microphone, as seen in Figure A1.5. Indeed, this happened on occasion. However, any such recordings resulted in a distortion of the sound and the resonance spectrum produced. Such distorted files were destroyed and the pitch in question re-recorded, and only viable recordings and their accompanying spectra were included in this appendix.

Resonance Spectrum of E4 With [i] Monophthong

Figure A1.1: E4, [i], Alberto Almarza

Figure A1.2: E4, [i], Lindsey Goodman

Figure A1.3: E4, [i], Alyssa Schwartz

With some minor variances among the three analyses, it may be seen by comparing the Power Spectrum of each that the spectral slopes for each decrease in a relatively linear manner with an increase in the frequency of the harmonics. The spectra for Almarza's and Schwartz's recordings reveals that the first formant (F1) falls on the first harmonic (H2). In Goodman's spectral analysis, H2 and H3 are equal in strength. For all three flutists, F1 and F2 fall on H2 and H3. F1 for all three recordings registers at approximately -5 to -10 dB, or 5-10 decibels below the zero-line at the top of the Power Spectrum screen. H13, H14, and H15 are significantly less present in the sound, averaging -42 to -63 dB among the three flutists.

Resonance Spectrum of E4 With [ɪ] Monophthong

Figure A1.4: E4, [ɪ], Alberto Almarza

Figure A1.5: E4, [ɪ], Lindsey Goodman

Figure A1.6: E4, [i], Alyssa Schwartz

The spectral slope of E4 produced with this monophthong is noticeably less linear than that produced with [i]. The highest harmonics of (H10-H15) are less present and less defined than the harmonics in the same pitch created in the [i] position, averaging -55 to -62 dB. The spectra for Almarza's and Schwartz's sounds show that the fundamental frequency (F0) is the strongest component of the sound, measuring -2 to -3 dB, with a more significant drop-off in the strength of H2 and H3 than in the previous position. H4 is significantly softer in both sounds followed by a spike in the presence of H5. The spectra for Goodman's sound shows that F1/ H2 (the first formant, which falls on the first harmonic) is the strongest component of the sound, followed closely by F2/H3, and H5 is significantly softer than either of the immediately-surrounding harmonics (a similar shape to the spectral slope of the other two flutists but displaced one harmonic higher). For Almarza and Goodman, F1 falls on H2 and F2 falls on H3 and for Schwartz, F1 falls on H2 and F2 falls on H5. The rise and fall of the spectral slope as the frequency increases is similar among the three flutists with some variance by one harmonic.

Resonance Spectrum of E4 With [ə] Monophthong

Figure A1.7: E4, [ə], Alberto Almarza

Figure A1.8: E4, [ə], Lindsey Goodman

Figure A1.9: E4, [ə], Alyssa Schwartz

The spectral slopes for E4 on the [ə] monophthong are somewhat more varied. F1 falls on H2 and F2 falls on H3 for Goodman and Schwartz's sound while F1 falls on H3 and F2 falls on H5 in Almarza's. The highest harmonics (H10-H15) in Almarza's and Schwartz's sound range between -53 to -58 dB and are not as clearly defined, where these same harmonics range from -31 to -49 dB and are more clearly-defined and linear in slope in Goodman's sound. All three flutists experience a noticeable dampening of H4 followed by a stronger peak of H5 and a dampening, again of H6.

Resonance Spectrum of E4 With [ʊ] Monophthong

Figure A1.10: E4, [ʊ], Alberto Almarza

Figure A1.11: E4, [ʊ], Lindsey Goodman

Figure A1.12: E4, [o], Alyssa Schwartz

For each flutist, the [o] monophthong yields weak and poorly-defined harmonics from H10-H15, averaging -57 to -66 dB among the three samples. F1 falls on H3 in Alberto's and Goodman's sounds and on H5 in Schwartz's sound, though all flutists' spectra show a similar pattern in that H3 is noticeably more present in the sound than H2, which is a unique trend for this monophthong. There is a more noticeable, sudden, and universal drop-off in the presence of the harmonics H9 and higher for this position than was observed in any of the previous positions.

Resonance Spectrum of E4 With [u] Monophthong

Figure A1.13: E4, [u], Alberto Almarza

Figure A1.14: E4, [u], Lindsey Goodman

Figure A1.15: E4, [u], Alyssa Schwartz

There are more noticeable inconsistencies among the spectral slopes of E4 produced with the [u] monophthong, particularly in the lower harmonics and F1 and F2. F1 falls on H3 in Almarza's sound but H2 in Goodman's and Schwartz's sound. However, in Goodman's sound, F1 is actually more present than F0. F2 falls on H2 in Alberto's sound, H3 in Goodman's sound, and H4 in Schwartz's sound. However, one noticeable similarity is that fewer high harmonics are present in these sounds. There is a significant dampening of the harmonics above H4 in Almarza's sound, H8 in Goodman's sound, and H7 in Schwartz's sound, and the harmonics become particularly undistinguished, especially in Almarza's and Schwartz's sound. The strength of the harmonics above H7 in Almarza's and Schwartz's sound average just -52 to -72 dB, which is noticeably more muted than the previous monophthongs.

Resonance Spectrum of E4 With [ɔ] Monophthong

Figure A1.16: E4, [ɔ], Alberto Almarza

Figure A1.17: E4, [ɔ], Lindsey Goodman

Figure A1.18: E4, [ɔ], Alyssa Schwartz

F1 and F2 fall on H2 and H3, respectively, in Almarza's and Goodman's sound, with F1 averaging approximately -7 dB softer than F0 for both. However, F1 falls on H3 and F2 falls on H5 in Schwartz's sound. Both Almarza's and Goodman's spectral analyses show a relatively linear slope for the lowest harmonics and all three readings show noticeably muted upper harmonics, with a significant decrease in their presence above H7 in Almarza's and Schwartz's sounds and H4 in Goodman's sound. The upper harmonics (H10-H15) in all three sounds are more dampened than any previous monophthong, ranging from -59 to -74 dB.

Resonance Spectrum of C5 With [i] Monophthong

Figure A1.19: C5, [i], Alberto Almarza

Figure A1.20: C5, [i], Lindsey Goodman

Figure A1.21: C5, [i], Alyssa Schwartz

It may be seen that the spectral slope of C5 produced with the [i] monophthong is much less linear in nature than E4 produced in the same position. For all three flutists, F1 falls on H5 and F2 falls on H3. F1 averages -12 to -21 dB softer than F0 and F2 averages -22 to -26 dB softer than F1. Additionally, each flutist's sound has a spike in power on H8 and H11, and the other upper harmonics between and above these are significantly muted and less clearly defined.

Resonance Spectrum of C5 With [ɪ] Monophthong

Figure A1.22: C5, [ɪ], Alberto Almarza

Figure A1.23: C5, [ɪ], Lindsey Goodman

Figure A1.24: C5, [i], Alyssa Schwartz

The spectra for Almarza's and Schwartz's sounds in this position reveal a similar slope to the previous monophthong, though the formants do not fall on the same harmonics, where Goodman's sound again displays a more linear slope. In Almarza's sound in this position, F1 falls on H7 and F2 falls on H4, in Goodman's, F1 falls on H2 and F2 falls on H3, and in Schwartz's, F1 falls on H3 and F2 falls on H2. The power of F1 and F2 in Almarza's and Schwartz's sound reflect a similar proportionality to the [i] monophthong, and all three flutists display a small peak of power on H7 with more muted higher harmonics.

Resonance Spectrum of C5 With [ə] Monophthong

Figure A1.25: C5, [ə], Alberto Almarza

Figure A1.26: C5, [ə], Lindsey Goodman

Figure A1.27: C5, [ə], Alyssa Schwartz

The spectral slope for all three flutists is somewhat more linear in this position than the previous two and display more muted upper harmonics. F1 falls on H3 and F2 falls on H2 in both Almarza's and Schwartz's sounds and F1 falls on H2 and F2 falls on H4 in Goodman's sound. The harmonics above H5 in the sound of all three flutists display a relatively linear decrease in strength with an increase in frequency, and the harmonics above H7 in all three average -6 dB softer than in the previous monophthong.

Resonance Spectrum of C5 With [ʊ] Monophthong

Figure A1.28: C5, [ʊ], Alberto Almarza

Figure A1.29: C5, [ʊ], Lindsey Goodman

Figure A1.30: C5, [ʊ], Alyssa Schwartz

The spectrum for each flutist on C5 produced with the [ʊ] monophthong reveals that F1 falls on H3 and F2 falls on H2. F1 averages -17 dB softer than F0 and F2 averages -7 dB softer than F1. The strength of the harmonics above H3 in Almarza's sound and above H5 in Goodman's sound reveal a relatively uniform dampening with an increase in harmonics, where there is a noticeable spike in the strength of H9 in Schwartz's sound. The harmonics above H7 for all three flutists average -5 dB softer than the same harmonics in the previous position.

Resonance Spectrum of C5 With [u] Monophthong

Figure A1.31: C5, [u], Alberto Almarza

Figure A1.32: C5, [u], Lindsey Goodman

Figure A1.33: C5, [u], Alyssa Schwartz

Where the spectral slopes of many of the previous positions have been somewhat linear or displaying a pattern of peaks and valleys, there is a rather distinctive drop-off and leveling of H3, H4, and H5 in the spectra of all three flutists in this position, averaging -17 dB softer than the fundamental frequency. F1 falls on H3 in and F2 falls on H2 in Almarza's and Schwartz's sounds where F1 falls on H2 and F2 on H3 in Goodman's. All flutists display an increasing dampening of the harmonics of higher frequencies until H6 (Almarza), H7 (Goodman), and H8 (Schwartz), where there is a spike in the power of the following harmonic. Though the upper harmonics in the sounds are less powerful, they are still relatively clearly defined.

Resonance Spectrum of C5 With [ɔ] Monophthong

Figure A1.34: C5, [ɔ], Alberto Almarza

Figure A1.35: C5, [ɔ], Lindsey Goodman

Figure A1.36: C5, [ɔ], Alyssa Schwartz

As with the [u] monophthong created on E4, the higher harmonics in the sound of each flutist are the most dampened on C5, averaging -49 to -54 dB from H7 to H9. F1 falls on H3 in Almarza's and Schwartz's sounds and on H2 in Goodman's sound. Save for a spike in the power of H6 in Schwartz's sound, each flutist displays a characteristic linear decrease in the power of each harmonic as the frequency increases.

Resonance Spectrum of A5 With [i] Monophthong

Figure A1.37: A5, [i], Alberto Almarza

Figure A1.38: A5, [i], Lindsey Goodman

Figure A1.39: A5, [i], Alyssa Schwartz

F1 falls on H3 and F2 on H2 in both Almarza's and Goodman's sounds and F1 falls on H2 and F2 on H5 in Schwartz's sound. There is an alternating pattern of every other harmonic being somewhat more present than those immediately surrounding it, with H2 tending to be softer than H3, which is much more powerful than H4, which is softer than H5.

Resonance Spectrum of A5 With [ɪ] Monophthong

Figure A1.40: A5, [ɪ], Alberto Almarza

Figure A1.41: A5, [ɪ], Lindsey Goodman

Figure A1.42: A5, [ɪ], Alyssa Schwartz

A5 performed with the [ɪ] monophthong displays many of the same traits as the previous position. F1 falls on H3 and F2 falls on H2 for all three flutists. H2 averages -4 dB softer and H3 averages -3 dB softer in this position than their counterparts for this pitch performed with [i]. In Goodman's and Schwartz's sound, H5 is, again, more present than H4, while H5 is slightly less powerful than H4 in Almarza's sound. Again, there is an alternating pattern of every other harmonic being somewhat more present than those immediately surrounding it, with H2 tending to be softer than H3, which is much more powerful than H4, which is softer than H5.

Resonance Spectrum of A5 With [ə] Monophthong

Figure A1.43: A5, [ə], Alberto Almarza

Figure A1.44: A5, [ə], Lindsey Goodman

Figure A1.45: A5, [ə], Alyssa Schwartz

The spectra of all three flutists for this monophthong are, again, quite similar, and they display similar tendencies as those observed in the previous two positions. One noticeable exception is that H5 in Schwartz's sound is significantly dampened, where this same harmonic is still quite present in Almarza's and Goodman's sounds. F1 falls on H3 and F2 on H2 for all three flutists, though the strength of these average -2 dB softer than in the previous position.

Resonance Spectrum of A5 With [ʊ] Monophthong

Figure A1.46: A5, [ʊ], Alberto Almarza

Figure A1.47: A5, [ʊ], Lindsey Goodman

Figure A1.48: A5, [ʊ], Alyssa Schwartz

This monophthong yields a more noticeable change in the spectral slope of A5 than the previous three, producing a more downward linear slope with increasing frequency once again. While the alternating spectral slope previously observed in the other positions on this pitch remains relatively true in Almarza's and Schwartz's sounds, this is not the case in Goodman's sound, which displays the most linear spectral slope of the three. F1 falls on H2 for Almarza and Schwartz and on a partial a fifth above the fundamental for Goodman, and from H3 and higher, the harmonics become steadily less powerful. The spike of power on H5 that was previously observed is no longer present in the sounds of any of the flutists.

Resonance Spectrum of A5 With [u] Monophthong

Figure A1.49: A5, [u], Alberto Almarza

Figure A1.50: A5, [u], Lindsey Goodman

Figure A1.51: A5, [u], Alyssa Schwartz

There are noticeable inconsistencies in the spectral slopes of A5 in this position among the three flutists. In Almarza's sound, F1 and F2 fall on H3 and H2, the odd-numbered harmonics tend to be significantly more dampened than the even-numbered harmonics, and H5 displays a spike in power as seen in previous spectra of A5. In Goodman's sound, F1 falls on a partial a fifth above the fundamental and F2 falls one octave above this, and the spectral slope is overall more linear save for a noticeable dampening of H3. In Schwartz's sound, F1 falls on H2 (and is equal in power to F0), F2 falls on H3, and the strength of the alternating harmonics mimics that seen in Almarza's sound. However, it is worth noting that the upper harmonics (H4 and higher) average -6 dB softer overall than the same harmonics of A5 played in the previous position.

Resonance Spectrum of A5 With [ɔ] Monophthong

Figure A1.52: A5, [ɔ], Alberto Almarza

Figure A1.53: A5, [ɔ], Lindsey Goodman

Figure A1.54: A5, [ɔ], Alyssa Schwartz

The spectra of this pitch played with the [ɔ] monophthong are more uniform among the flutists, with the spectral slopes being overall more linear and the familiar pattern of even-numbered harmonics being more powerful. F1 falls on H2 in Almarza's and Schwartz's sound and on H3 in Goodman's sound (H3 is only 1 dB more powerful than H2). H5 is not particularly powerful in any of the spectra, and the higher harmonics (H4 and higher) average -9 dB softer than the previous position.

Resonance Spectrum of G6 With [i] Monophthong

Figure A1.55: G6, [i], Alberto Almarza

Figure A1.56: G6, [i], Lindsey Goodman

Figure A1.57: G6, [i], Alyssa Schwartz

The spectra of G6 played with the [i] monophthong are quite consistent among the three flutists. For each, F1 falls on H3 and F2 falls on H2 with significant dampening of all other overtones in the sound. Among the three flutists, F1 averages -12 dB softer than F0 and F2 averages -23 dB softer than F0.

Resonance Spectrum of G6 With [ɪ] Monophthong

Figure A1.58: G6, [ɪ], Alberto Almarza

Figure A1.59: G6, [ɪ], Lindsey Goodman

Figure A1.60: G6, [ɪ], Alyssa Schwartz

The spectra for G6 played with the [ɪ] position are, again, quite uniform among the flutists and are very similar to the previous monophthong. However, F1 (again, falling on H3) averages 4 dB stronger and F2 (again, falling on H2) averages -7 dB softer than the first two formants of G6 produced with the [i] position.

Resonance Spectrum of G6 With [ə] Monophthong

Figure A1.61: G6, [ə], Alberto Almarza

Figure A1.62: G6, [ə], Lindsey Goodman

Figure A1.63: G6, [ə], Alyssa Schwartz

F1 falls on H2 and F2 falls on H3 in Goodman's and Schwartz's sounds, where the opposite is true for Almarza's sound. F1/ H2 is proportionally stronger by an average of 8 dB than F2/H2 in the previous position while F2/ H3 averages -11 dB softer than F1/H3. F1 averaged -11 dB softer than F0 in the previous position but is more dampened here, averaging -18 dB softer. The strength of F2 in relation to F0 is similar to the previous example, however, averaging -27 dB softer in both positions.

Resonance Spectrum of G6 With [ʊ] Monophthong

Figure A1.64: G6, [ʊ], Alberto Almarza

Figure A1.65: G6, [ʊ], Lindsey Goodman

Figure A1.66: G6, [ʊ], Alyssa Schwartz

Where Goodman's and Schwartz's sounds produce a spectral slope very similar to those seen in the previous examples on this pitch, Almarza's sound in this position yields somewhat different results, with increased power on two nonharmonic overtones in addition to H2 and H3. However, both Almarza and Goodman produce a sound in which F1 falls on H3, where Schwartz's spectrum shows that F1 falls on H2. F2 falls on a nonharmonic overtone in Almarza's sound, on H2 in Goodman's sound, and on H3 in Schwartz's sound. All three flutists display the characteristic peak in power of H3, and this harmonic is actually proportionally stronger in comparison with F0 by 8 dB than in the previous position.

Resonance Spectrum of G6 With [u] Monophthong

Figure A1.67: G6, [u], Alberto Almarza

Figure A1.68: G6, [u], Lindsey Goodman

Figure A1.69: G6, [u], Alyssa Schwartz

For all three flutists, F1 and F2 fall on H3 and H2, respectively. The relative power of F1 in comparison with the fundamental frequency is quite consistent with the previous example, varying only by 1 to 2 dB. However, F2 averages -6 dB softer in comparison with F0.

Resonance Spectrum of G6 With [ɔ] Monophthong

Figure A1.70: G6, [ɔ], Alberto Almarza

Figure A1.71: G6, [ɔ], Lindsey Goodman

Figure A1.72: G6, [ɔ], Alyssa Schwartz

These spectra are somewhat inconsistent, with Goodman's and Schwartz's sounds revealing a spectral slope similar to much of what has been seen on this pitch and Almarza's sound producing a more linear slope. F1 falls on H3 and F2 falls on H2 in Goodman's sound where the opposite is true for Schwartz's sound. Interestingly, the formants fall on nonharmonic overtones in Almarza's sound. H5 averages -10 dB softer in this position than the previous and is more dampened in this position for G6 than any previous position.

Appendix 2

Resonance Spectra of Three Violins

Figure A2.1: E4, Three Violins

The power of H2, H3, H4, H5, and H7 are quite close to each other, varying by only 3 dB and averaging -4dB softer than F0. F1 falls on H5 and F2 falls on H3. There is noticeable dampening of H8 and H9, followed by a spike in power of H10 and a somewhat more linear slope for the remaining high harmonics.

Figure A2.2: C5, Three Violins

On this pitch, F1 falls on H3 and F2 falls on H2, with F1 sounding -12 dB softer than F0 and F2 sounding -16 dB softer than F0. The spectral slope is overall linear with a strengthening of H3 and H7. There is a more significant decrease in the power of the higher harmonics above H7.

Figure A2.3: A5, Three Violins

For A5 as played by a group of violinists, F1 falls on H2 and F2 falls on H4. There is a somewhat alternating spectral slope, with H3 being softer than the harmonics immediately surrounding it (H2 and H4) and H5 similarly being dampened in comparison with H4.

Figure A2.4: G6, Three Violins

For this pitch, F1 falls on H5 and F2 falls on H9. F1 is -9 dB softer and F2 is -12 dB softer than F0. There is significant dampening of H2, H3, H4, H6, H7, and H8, which average -43 dB softer than F0, F1/H5, and F2/H9.

Resonance Spectra of the Clarinet

Figure A2.5: E4, Clarinet

In the resonance spectrum of E4 as played on the clarinet, F1 falls on H3 and F2 falls on H9, with F1 sounding -13 dB softer than F0 and F2 sounding -17 dB softer than F0. H2 and H4 are significantly dampened in comparison with H3 and H5, producing a somewhat alternating spectral slope. However, the slope becomes much more linear overall from H9-H15, with the power of these harmonics decreasing with an increase in frequency.

Figure A2.6: C5, Clarinet

For this pitch on clarinet, F1 falls on H3 and F2 falls on H4. Interestingly, F1 is actually 1 dB stronger than F0, while F2 is -10 dB softer. There is noticeable dampening of H2 and H8 and a spike in power of H9. The spectral slope is less linear overall than that of the previous pitch, with alternating tendencies from H2-H4 and H7-H9 and a plateau in H5-H7.

Figure A2.7: A5, Clarinet

In the resonance spectrum for A5 on clarinet, F1 falls on H2 (-9 dB softer than F0) and F2 falls on H4 (-10 dB softer than F0). There is a somewhat alternating spectral slope, with H3 being softer than the harmonics immediately surrounding it (H2 and H4) and H5 similarly being dampened in comparison with H4.

Figure A2.8: G6, Clarinet

For G6 as played on clarinet, F1 falls on H9 and F2 falls on H5. F1 sounds -9 dB softer than F0 and F2 sounds -17 dB softer than F0. There is significant dampening of H2, H3, H4, H6, H7, and H8, which average -49 dB softer than F1 and F2 and -58 dB softer than F0. There is a small spike in power on H7 of 9 dB in comparison with the other dampened harmonics.

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