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Acoustics of Vowel Articulation in Flute Playing

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West Virginia University

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Acoustics of Vowel Articulation in Flute Playing

Jose Fernando Ramirez

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ACOUSTICS OF VOWEL ARTICULATION IN FLUTE PLAYING

Jose Fernando Ramirez-Macias

Thesis submitted
to the Eberly College of Arts and Sciences
at West Virginia University

in partial fulfillment of the requirements for the degree of

Master of Arts in
Linguistics

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Keywords: Flute, vowels, acoustics, fundamental, overtones, tone, music, linguistics

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ABSTRACT

Acoustics of vowel articulation in flute playing

Jose Fernando Ramirez-Macias

Through an experiment and series of acoustic analysis, this thesis evaluates if vowel articulation modifies flute sound. It is an initial investigation in a sequence of research on linguistics solving major questions in flute performance and teaching, and is a continuation of a previous pilot project called “Acoustics and Perception of Speech Sound on the Flute,” where participants attempt to distinguish vowel articulation of the mouth while playing the flute. In this thesis, the flute sound is tested acoustically to provide evidence of how vowels alter the timbre. To this end, a professional flutist recorded A=440 Hz in the three octaves of the flute. The participant played one pitch while shaping the mouth using one monophthong. The first recording used peripheral vowels on the IPA, while in a second recording the flutist played vowels contrasting in jaw height on the IPA, therefore producing a total of thirty samples. The collected data was evaluated using spectra analysis, overall loudness, and specific spectral prominences to explain in different dimensions how flute sound behaves in isolation.

The results did not show consistent evidence proving timbre differences. The changes in spectra are small, not related to vowel articulation and quality, giving random results within a specified range. The results provide evidence that the acoustics of phonetic vowels do not correspond to flute sound; rather, different phenomena govern them.

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CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	iii
CHAPTER I: INTRODUCTION.....	1
1.1 Introduction.....	1
1.2 Technical background	2
1.2.1 Vowels	2
1.2.2 Flute.....	7
1.3 Theory: interactions between flute and vocal tract.....	9
1.3.1 Previous research: scientific research and claims about flute sound and vowel articulations.....	9
1.3.2 Linguistic claims - reasons to doubt the utility of vowel shapes in flute sound.....	11
1.3.2.1 Effects of vowel should depend on speaker, flute, and note.....	11
1.3.2.2 Filtered aerodynamic output: lips and embouchure.....	12
1.3.2.3 Flute players and phonated vowels	12
1.3.2.4 Biomechanical effects.....	13
1.3.2.5 Summary.....	13
CHAPTER II: RESEARCH	15
2.1 Introduction	15
2.2 Methods.....	16
2.2.1 Recording details	17
2.2.2 Recording instructions.....	17
2.2.3 Flutist background	18
2.3 Evaluated acoustic properties	18
2.4 Results.....	19
2.4.1 IPA vowel sets.....	19
2.4.2 Shape of spectra analysis	21
2.4.2.1 Fundamental - A 440Hz.....	21
2.4.2.2 Fundamental - A 880Hz.....	24
2.4.2.3 Fundamental - A 1760Hz.....	26
2.4.3 Overall loudness.....	28
2.4.3.1 Fundamental - A 440Hz.....	28
2.4.3.2 Fundamental - A 880Hz.....	30
2.4.3.3 Fundamental - A 1760Hz.....	31
2.4.3.4 Combination of all vowels in all registers.....	33
2.4.4 Specific spectral prominences	34

2.4.4.1 - 880Hz specific spectral prominences.....	35
2.4.4.2 - 1760Hz specific spectral prominences.....	36
CHAPTER III: DISCUSSION	38
3.1 Results - summary	38
3.1.1 Measure correlation between series.....	40
3.2 Conclusion.....	41
3.3 Pedagogical implications.....	43
3.4 Pilot perception study.....	43
3.5 Future studies.....	44
APPENDIX.....	46
REFERENCES.....	55

CHAPTER I: INTRODUCTION

1.1 Introduction

The beginning of this paper concerns itself with finding particular, pre-existing conventions as to how vowel articulations¹ could affect the western traverse flute sounds. This research systematically highlights relevant information with a narrowed focus on a two-part hypotheses. This thesis will discuss more precisely how vowel articulation without voicing may affect sounds within the flute guided by the hypothesis that, if so, humans could have the ability to detect the articulated vowels in isolation and in a series. Nonetheless, this work itself does not discuss some aspects of flute technique such as vibrato, tonguing, dynamics, and simultaneous voice/flute sound instances. The reason for this is to isolate the proposed phenomena at hand with the goal of precisely assessing the acoustic and perceptual aspects of subsequent research.

Overall, physical/linguistic and flutist aspects are taken into account, noting on one hand that the oral cavity and the flute are in a sense two different instruments with which music can be influenced. Since there is no additional, inserted, or assistive device in the mouth, such as a reed, used to control the way sound is produced, there should not be any significant changes in aspects of timbre if the flutist generates changes within the oral cavity. This would appear to make vowel changes difficult for the listener to identify. In contrast, expert flutists utilize different vowel shapes, claiming that the resonance spectrum or monophthongs make it possible to blend the sound with other instruments and produce different resonance qualities in a instrument. In such

¹ Articulation for wind instruments is also referred to as tonguing. It is a technique that allows performers to use the tongue to separate and enunciate the beginning of the sound. In this work, word articulation takes its meaning from linguists, which refer to a broad range of change of the configuration of the vocal tract.

an instance, the oral cavity modifies the energy produced by the lungs, hence suggesting that the quality of sound changes is wavering, and humans should be capable of detecting such variances or changes. The methodology of this work aims to solve through experiments how vowel shapes affect sounds in the flute and detect if humans can identify vowel changes in flute sound.

1.2 Technical background:

This section discusses the main concepts and elements of this work, which concerns vowel articulations from an acoustic point of view and flute sounds from an acoustic and physics perspective. Finally, it assesses if the combination of vowel shapes will affect flute sound.

1.2.1 Vowels

Vowels are used mainly in speech. Linguists have exhaustively studied this phenomenon in order to understand it in depth. The following is a summarized explanation of how humans produce vowels and how vowels are measured.

When speaking, humans produce vowels by allowing air to pass through the vocal folds (Johnson 2010), which consist of a two-part tissue that vibrates while air moves through the vocal tract. The shape of the vocal tract determines the resonant frequencies of the sound that comes out of the mouth. The vowel quality changes when the shape of the vocal tract changes; linguists have characterized these changes principally in three dimensions (high - low, front - back, rounded and unrounded). The IPA (International Phonetic Alphabet) vowels are illustrated in *Figure 1 chart of vowels*.

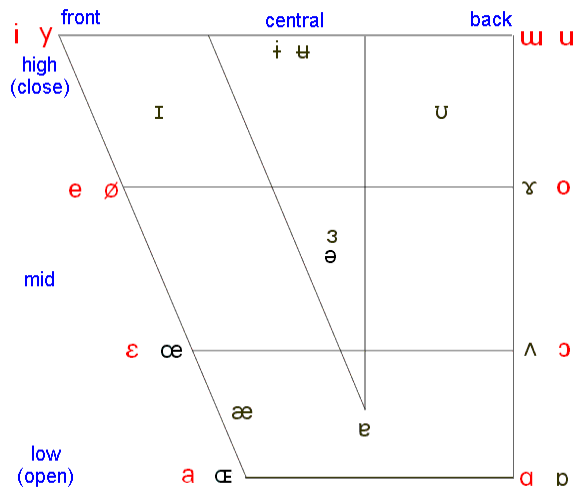


Figure 1. IPA (International Phonetic Alphabet). Vowel chart.

Vowels are measured using a spectrogram, which identifies the formants (the frequencies that determine the phonetic quality of a vowel) and is the combination of two elements: the harmonic spectrum of sound from the vocal folds and the resonance of the vocal tract. *Figure 2* shows the individual phenomena of resonance. First, it shows the resonances of the vocal tract, then the harmonic spectrum of the sound from the vocal folds, and finally, the bottom image is a combination of both. *Figure 3* shows a representation of the vocal tract in vowels [a], [i], and [u]. *Figure 3* also illustrates the resonance and harmonic spectra of the abovementioned vowels. The Y-axis measures loudness and the X-axis measures Hertz (Hz). The spectrograms assemble a variety of spectra at different time points to visualize how energy at various frequencies changes over time (see *Figure 4*). (Praat is a free computer software used to perform scientific analysis of speech in phonetics.)

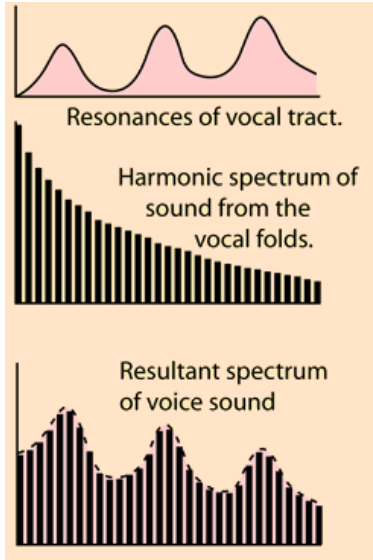


Figure 2. Resultant spectrum resonance and harmonic spectrum.
<http://hyperphysics.phy-astr.gsu.edu/hbase/Music/vocres.html>

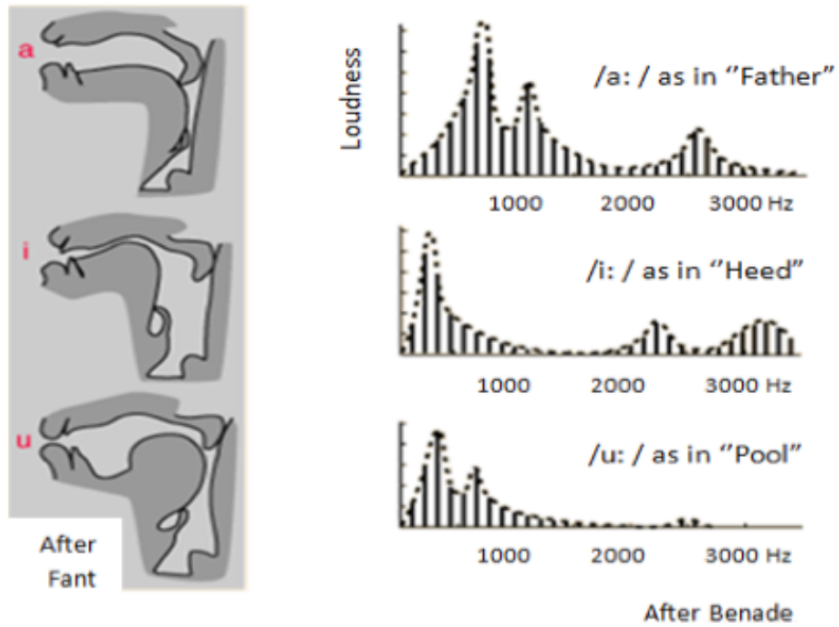


Figure 3. Schematic cross section of vocal tract of a male speaker for the three vowels [a:], [i:] and [u:]. Modified from <http://hyperphysics.phy-astr.gsu.edu/hbase/music/vowel.html>.

Figure 4 is a spectrogram of the vowels [i], [u], and [a] in the software “Praat.” The red arrows show the values of formant 1 and formant 2. The Y-axis denotes Hertz values and the X-axis represents time.

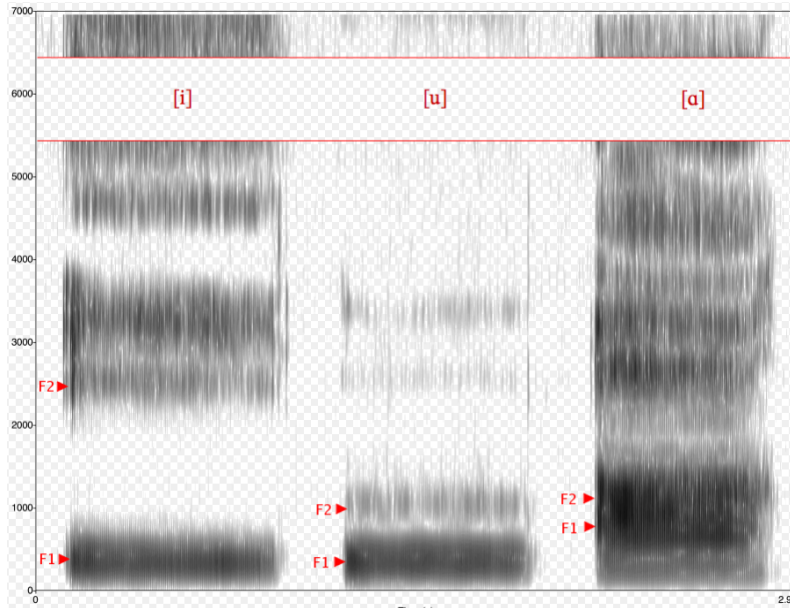


Figura 4. Formants in Praat of [i], [u], [a].

If vowels are measured in formant 1 and formant 2, the values in *Table 1* are expected. Nevertheless, those values are going to vary for different individuals depending on several factors, including gender and age.

Table 1		
<i>Average F1 and F2 values for female English speakers'</i>		
Vowel	F_1 (Hz)	F_2 (Hz)
i	437	2761
e	536	2530
ɪ	483	2365
u	459	1105
ʌ	753	1426
ɛ	731	2058
a	555	1035
æ	669	2349
F_1 = Formant 1		
F_2 = Formant 2		

Table 1

Although there is not an exact measurement for every person, the vowels could be represented in a plot similar to *Figure 5*. Setting formant 1 and formant 2 in the following figure will roughly recreate the image of the IPA plot shown in *Figure 1*. In order to achieve this graph, F2 requires the values to be more compacted than F1. Altering the configuration of F1 and F2 would give a different result.

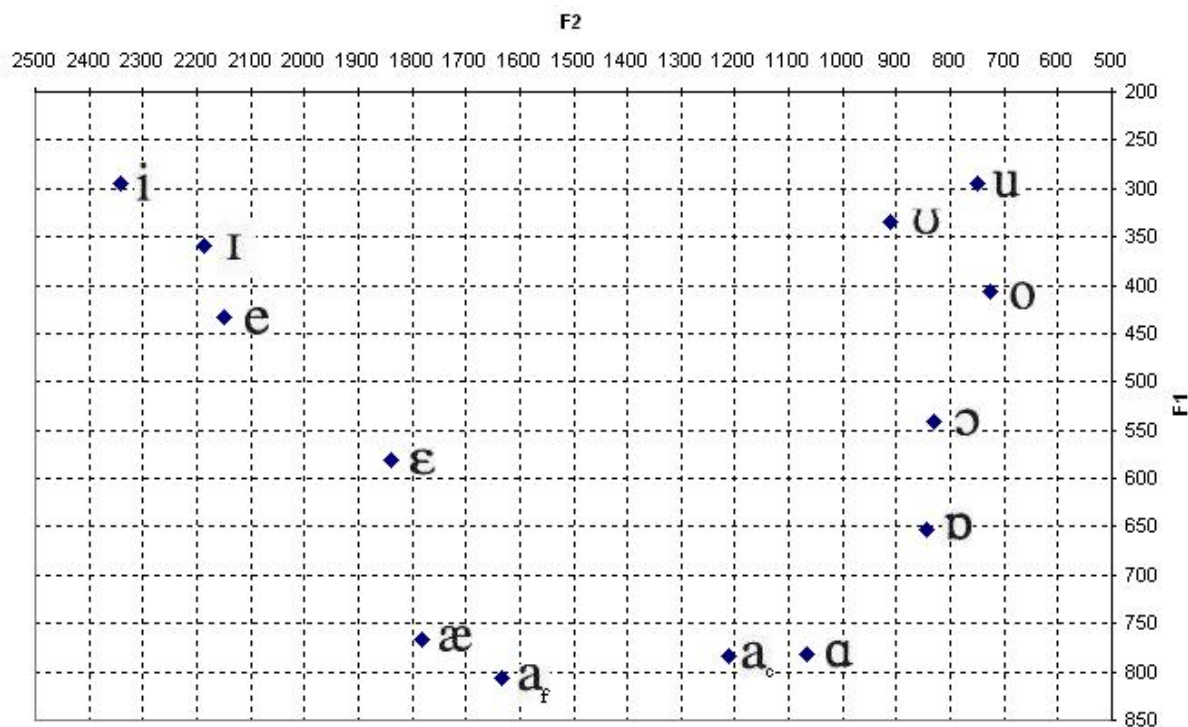


Figure 5. Representation of formant 1 and formant 2 in vowels.

1.2.2 Flute

The term flute in this thesis refers to the western traverse flute. In simple terms, a flute is a cylindrical instrument with holes. The embouchure is where the flutists place the mouth and where air goes in. Modern flutes are made out of metal, but it remains part of the woodwind family of orchestral instruments. In its evolution, the flute changed from wood to metal and added keys. As a whole, most flutes are made of nickel, silver, gold, or a combination of these metals. The system of keys developed by the musician and inventor Theobald Böhm (1794 – 1881), allows the instrument to go through the chromatic scale.

To produce sound, the flutist produces a rapid air jet coming from the lungs. That air jet is energy that goes through the vocal apparatus and is condensed in the lips. The air goes out of the lips hitting the embouchure at a speed anywhere between 20 to 60 meters per second, depending on the pressure impressed by the flutist. When air hits the embouchure, the jet is divided in two; one part of the power goes inside the flute while the other flows outside. That phenomenon produces vibration that resonates in the instrument, thus projecting sound.

Figure 6 shows the breathing process: inhaling expands the chest and contracts the diaphragm, while exhaling contracts the chest and relaxes the diaphragm. *Figure 7* illustrates how the lips direct air into the flute, then the air-power hits the embouchure, which divides the air in two – one part of the air goes inside and other outside of the instrument.

Rebound Breath: Technique For Singers And Wind Players

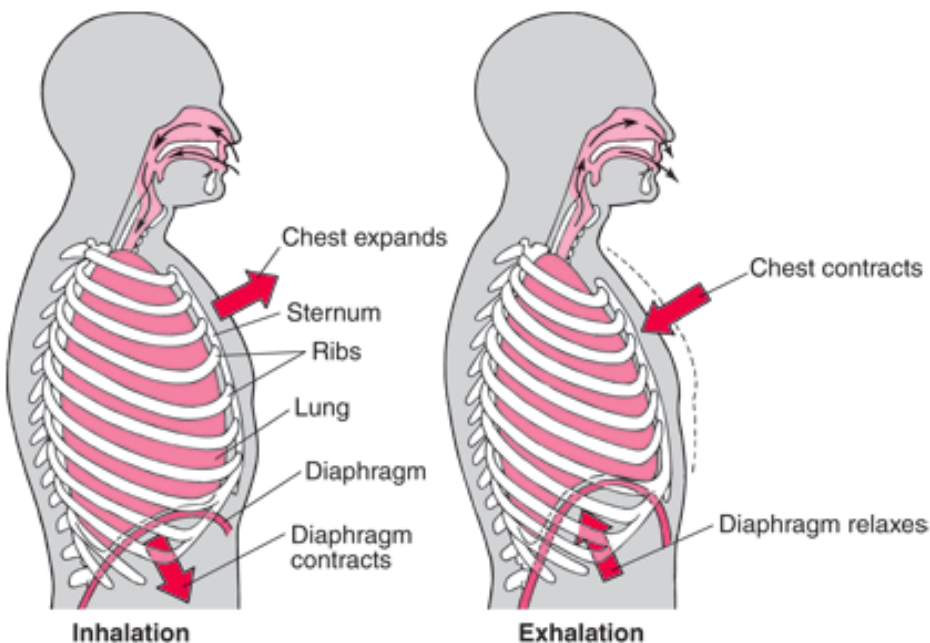


Figura 6. Rebound Breath: Technique for Singers and wind players.

<http://marlenehartzler.com/rebound-breath-technique-for-singers-and-wind-players/>

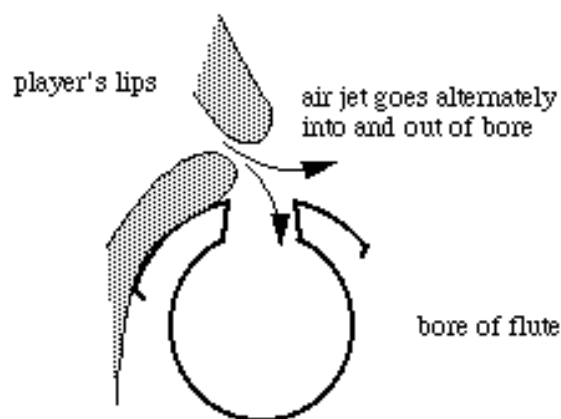


Figura 7. Flutist embouchure <https://newt.phys.unsw.edu.au/jw/fluteacoustics.html>

1.3 Theory: interactions between flute and vocal tract

1.3.1 Previous research: scientific research and claims about flute sound and vowel articulations

Research papers (Gerda 2006, Schwartz 2018, Walker 1995, Walter 1978), internet pages (Miyasawa) and videos (Cela 2012) make claims supporting the theory that the vowel shapes inside the mouth directly affect the sound of the flute. Most of the arguments suggest that the chosen vowel manipulates the air going through the vocal tract, changing the vowel articulations, affecting the jet of air from the mouth, and altering the relative amplitude of harmonics in the flute. The effect in the spectral properties of the note is changed; the color (timbre) of the sound is different (Walker 1995) because some vowels seem to help produce a better tone than others in the flute (Walter 1978). Adding more color to music makes it more interesting, similar to painters using a wide variety of colors in their work (Gerda 2006); the colors in music are associated with

the frequency in the spectra. Although there is no exact consensus, there is a general notion of relation between sound and qualities of matter. For instance, experts may say 'bright' and 'light' referring to sounds with more high-frequency energy in their spectra, and 'warm' and 'dark' refer to sounds with more low-frequency energy in their spectra. However, there are no exact measurements of when something is 'bright' or 'dark'. Additionally, "certain vowel positions yield a more or less homogenous blend with different instruments in their 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." (Schwartz 2018). The overtones are changed; therefore the color of the instrument changes. (Wincenc 1998:86).

The famous Irish flute virtuoso James Galway affirmed in 1982 that the tone of the flute is directly related to singing. He compares the techniques of the flute to singing techniques. Arguing that flutists should warm up as a singer does, a singer will use vowel sounds only, rather than words. He says that each vowel has a distinct sound, a different color, which the flute player can reproduce. The UK flutist Clarine Southworth also supports this idea, writing in 2010 for the internet page of Miyazawa, one of the most famous flute manufacturers in the world: "...vowels have the ability to add an open and warm quality and the articulation will create the drive and excitement" (Southworth 2010).

According to Mayles (2017), by using back vowels such as [u] and [a], the flutist achieves ‘bright’ colors in sound. By using high vowels [i] and [u], the colors are ‘darker’(Mayles 2017). The low vowels enhance louder and open sound, resulting in a warm tone. High vowels contribute to the articulation in the flute (the rapid stopping and starting of the airstream) by separating the stream of air blown in the flute because of their close proximity on the roof of the mouth (Clare 2010).

1.3.2 Linguistic claims: reasons to doubt the utility of vowel shapes in flute sound

1.3.2.1 Effects of vowel should depend on speaker, flute, and note

From an acoustic point of view, there are several reasons to doubt the theory proposed to the flutist. The information collected about vowels and acoustics does not match the assumptions of vowel shapes changing the timbre of the instrument. Nevertheless, in the case that the claim that vowel forms change the color of the flute is correct, there are many factors that should be considered. It is required to know at least the gender and the age of the flutist, as these factors change the spectrum values in vowels used in speech. People have different characteristics affecting vowel resonances due to varying vocal tract sizes and shapes. Also, the resonance spectrum of the flute and the pitch played affect the results. Different flutes have different spectra depending on the flute cavity shape. Other factors such as the thickness of the material, the material itself, the quality of the instrument, and the experience of the flutist also impact the overall results. All these variables change drastically in real life, thus the chances of different flutists reproducing the same results are unlikely.

1.3.2.2 Filtered aerodynamic output: lips and embouchure

From an acoustic perspective, there are reasons to be skeptical about the flutists' claims of vowel articulations changing the timbre of the instrument. The lips in these phenomena work as a baffle. Imagining that some of the properties of the vowel could be transferred through the jet stream, those vowels would be filtered through the narrowed lips of the player. Even if a part of the information survives that filter, the aerodynamic output will hit the embouchure-hole and transfer the remaining property to the body of the flute. That resonance would destroy any vestige of vowel property. It is important to highlight that the flute has its own resonant frequencies that cannot be changed by the mouth. Changing the instrument shape will result in manipulation in timbre. The vowels in speech change because the resonance occurs in the mouth and, due to this cavity's ability to resonate sound, vowels are produced.

1.3.2.3 Flute players and phonated vowels

From a linguistic phonetic perspective, the claim of vowel shapes modifying flute sound lacks substantial argument. In traditional flute playing, the flutist does not produce phonated vowels. That is to say, the process of voicing never starts; the vocal folds do not move and, ideally, nothing interferes with allowing the jet stream to go into the flute. As a result, the flute produces a noisy jet-stream in which overtones are already set and give the characteristic sound of the instrument. Those are two distinct phenomena which work differently. It is possible to produce phonated vowels while playing the flute; however, its results and implications do not concern this work.

1.3.2.4 Biomechanical effects

The above-stated reasons support a skeptical position from an acoustic point of view. However, even if there are no effects on the flute's spectrum (timbre), there are biomechanical effects that could interfere or allow loudness, which means that there should be parts of the body that could alternate the intensity (volume) of the sound.

Humans move parts in the vocal tract while speaking, including parts in the larynx, mouth, etc. Flutists do the same while playing. However, the position of the jaw or lips could change the angle or velocity of the jet stream hitting the embouchure-hole. Additionally, interference in the vocal tract would decrease the speed of air. Both position and angle affect energy transfer from the lungs to the flute.

The biomechanics should not affect the relative energy of different fundamental and overtones, the overtones are going to remain in their positions of the flute, but it could change overall loudness (volume).

1.3.2.5 Summary

Overall, vowels have negligible effect on flute acoustics because of external factors that impede the transfer of vowel quality to the flute, such as speaker, flute, and note, which all change drastically between each person. The sound is filtered through the lips and embouchure, which would destroy any transfer of the vowel quality. There are two different physical phenomena that apply to flute playing and phonated vowels which operate separately to produce sound. Even

considering scepticism regarding the previously stated factors, the biomechanical effects of the flutist could affect the flute sound in volume in ways that the others factors do not. Expert implementation would be required in order to take these external factors into account. Even then, it is nearly impossible to predict a single note when measuring these factors.

CHAPTER II: RESEARCH

There are pieces of evidence from two perspectives. One supports a theory where the vowel shapes manipulate flute spectrum (timbre, color) while the other is skeptical of manipulation. A test was designed to prove the potential consequences of vowels shapes. If there is any change, there must be scientific evidence that shows those differences and suggests an answer that denies or supports a side of the previous claims. Moreover, the results must show changes in the spectrum or gross intensity of the flute sound.

2.1 Introduction

In order to perform this experiment, an experienced flutist who had a thorough of knowledge of the theory of vowel articulations was recorded. This flutist not only incorporates this theory into her own performance but also her research. This affords the best likelihood to listen and compare the effects of this test. The recording contained samples of the player using different vowel shapes. The vowels contrasted drastically with each other to show a large amount of variation. In this experiment, a series of cardinal points in the IPA chart were recorded, followed by a set of front vowels. The recording had two pairs of samples of [i] and [e] to check for consistency. [u] is the only rounded vowel in the set; therefore, if there is any difference in rounding, this vowel articulation might show it. All samples were evaluated to see the spectrum and overall intensity of the flute sound. The software “Praat” is typically used to analyze speech, however, it was modified to analyze flute sound for the purpose of this experiment. A Praat script was configured to detect flute sound instead of human voice. It measured energy in the

fundamental, first and second overtones, total intensity (volume), energy at the onset and the end of the note. Through this analysis, it is possible to identify the effect in vowel shape on the spectrum or gross intensity of flute sounds. Once the data is collected and organized, graphs can be designed in a spreadsheet to compare the given information visually.

This thesis is an exploratory study. A follow-up experiment with more data will be considered if there are remarkable patterns in the results. Although this study provides a limited data set as a first attempt, it provides enough information to make assumptions and generalizations about the topic and determine if it is worthwhile for students and researchers to continue inquiring.

2.2 Methods

This section explains the procedures carried out for this experiment, including the order of recording material and details about the setup, performance, and flutist.

Thirty samples from three tones were taken into account. The recorded tones were: A4= 440Hz, A5= 880Hz and, A6= 1760Hz. The performer played each pitch shaping the oral cavity while playing in the following pattern: 1) [i] as in "need" (High – front – unrounded vowel), 2) [e] as in "wait" (high-mid front unrounded vowel), 3) [u] as in "boot" (High – back – rounded vowel), 4) [ʌ] as in "fun" (low-mid – back – unrounded vowel), and 5) [a] as in "car" (Low – back – unrounded vowel).

To carefully investigate the impact of higher and lower vowels and analyze consistency, the flutist was recorded a second time playing the same notes. However, the performer followed a

different order: 1) [i] as in "need" (High – front – unrounded vowel, the tongue body is advanced forward and the corona approximates the hard palate), 2) [ɪ] as in "bit" (near-high – front – unrounded vowel) 3) [e] as in "wait" (high-mid – front – unrounded vowel), 4) [ɛ] as in "bed" (low-mid – front – unrounded vowel), and 5) [æ] as in "cat" (near-low – front – unrounded vowel). This order evaluates front vowels according to height, which contrasts with the previous cardinal vowels recording. Therefore, comparisons between the sound in various vowel dimensions, such as high–low, front/unrounded–back/rounded, can be drawn.

2.2.1 Recording details

The recordings have minimal external sound and no vibrato. The recording environment was a non-sound proof, but reasonably quiet, room. A head-mounted microphone was used to record and the flute was a gold Muramatsu. The flutist pronounced the vowel or a word where the vowel is included a few times before playing to ensure the shape of the mouth maintained the position of the isolated vowel while playing. However, the flutist did not produce sound in the vocal folds while playing.

2.2.2 Recording instructions

While playing A4(440Hz), shape the mouth as one vowel, hold the note for four seconds. Follow this order to record in the first recording [i], [e], [u], [ʌ] and [a]. Leave silence space between each vowel. In a second recording follow this pattern [i], [ɪ], [e], [ɛ] and [æ]. Repeat the same process for A5(880Hz) and A6(1760Hz).

Recording #1: [i], [e], [u], [ʌ] and [a].

Recording #2: [i], [ɪ], [e], [ɛ] and [æ].

2.2.3 Flutist background

The flutist recorded in this thesis is a talented and successful. The performer has won several competitions and prizes during her career, was part of the Flute Studio at West Virginia University, and finished her master and doctoral degrees at the same institution.

2.3 Evaluated acoustic properties

The first part of the evaluation concerns the spectral properties of each recorded pitch and vowel. In phonetic vowels, the intensity of each overtone indicates the changes (principally in values of formant 1 and formant 2). In this study, the fundamental, overtone 1, and overtone 2 are evaluated in A 440Hz, A 880Hz, and A 1760Hz. The intensity in different fundamental and overtones would indicate the change of the used vowel.

The second part of the evaluation concerns overall loudness in each pitch, The note is isolated and compared in vowel height in front vowels in IPA chart, *Figure 8*. The goal is to have overall loudness in each vowel and tone, and the final result is obtained by adding the values of the fundamental and the first and second overtones of the note. Additionally, the difference in loudness is measured by comparing the fundamental and overtones; fundamental - overtone 1 and overtone 1 - overtone 2. Finally, the energy on the onset and end of the note is determined.

The third part of the test uses A 880Hz as a fundamental compared with the first overtone of A 440Hz, which is also A 880Hz. The measurement in phonetic vowels notoriously changes. Therefore, it could show a high contrast in the flute, as in speech vowels. The same procedure is made using A 1760Hz as a fundamental, it is compared with the first overtone of A 880Hz, which is also A 1760Hz. That measurement is taken at the beginning of the note.

2.4 Results

This section discusses in detail the sample recording procedures of the experiment. The first process consists of organizing the data in IPA vowel plots. This method of organization allows for evaluation of every pitch and vowel from two perspectives, a shape of spectra analysis, and overall loudness. Finally, the specific spectral prominences explanation concludes the previous findings. The terms mentioned above are clarified and expanded in each section of the chapter.

2.4.1 IPA vowel sets

Figures 8 to 10 are IPA (International Phonetic Alphabet) charts. They separate the recording into different categories. *Figure 8* shows all vowels played by the flutist in the experiment. *Figure 9* illustrates the cardinal points taken in the first recording; *Figure 10* shows all front vowels taken in the second recording. Each phoneme has a number that is measured on a scale that was designed for this experiment. This number shows the height of the vowel, one being the lowest and five the highest; the measurement is used in overall loudness and spectral

prominence. Vowels [i] and [e] meet the criteria of cardinal and front vowels. This repetition checks consistency in the results.

VOWELS

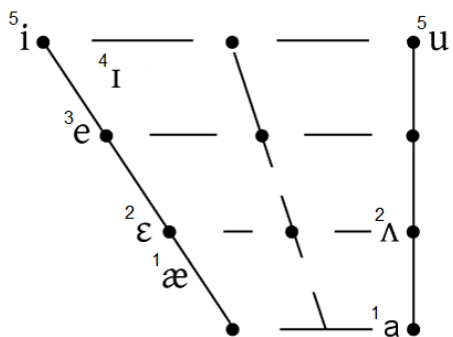


Figure 8. IPA Chart. Set of all vowels recorded

VOWELS

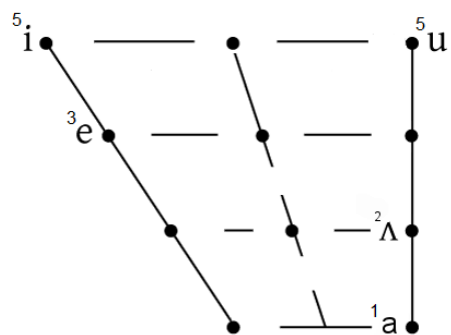


Figure 9. IPA Chart. Set of cardinal points. Recording # 1

VOWELS

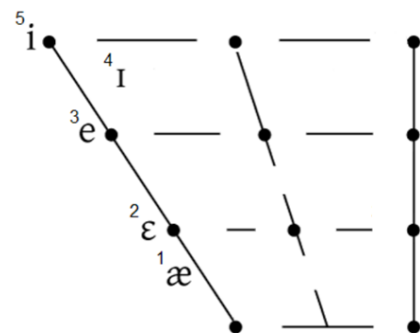


Figure 10. IPA Chart. Set of front vowels. Recording #2

2.4.2 Shape of spectra analysis

This section organizes all results and displays them in their spectral property for each pitch. The spectrum of the note is explained first using cardinal vowels, followed by front vowels. Although the real recordings do not always indicate an exact value of Hertz, they are in the same category. Therefore, the results are accurate. For each note, the chart on the left side shows the labels and values used in the graphs on the right side.

Each chart has five columns. The first column specifies the octave of the flute; the second column shows the used vowels, followed by the solfège syllables, and the Hertz. The next three columns present the energy (decibels) in the evaluated frequencies: the fundamental, first overtone and, second overtone, which in the script were realized as a1db, a2db and, a3db. To make it more intelligible, both labels are above the values. Additionally, some of the decimals in the results were deleted for practical purposes.

2.4.2.1 Fundamental - A440Hz

The first note to analyze is A 440Hz (first octave of the flute) — the explanation evaluates its spectral properties from two perspectives: cardinal vowels and front vowels.

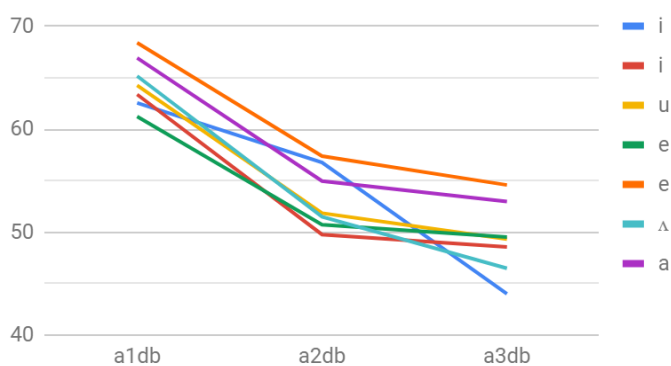
Graph 1 is a representation of the values shown in *Table 2*. It displays the decibel in A 440Hz using cardinal vowel in the fundamental and its overtones. *Graph 1* shows that all vowels have the same shape in backness and in height except one, [i]. If there were a correlation with a phonetic vowel, the line shapes should look different in their overtones, not solely upper unlike the others, with a remarkably similar shape. The pairs of [e] have the same form and are covering

most of the possible spectrum of the other vowels; it suggests the same shape but in different locations. The [i] with different measures must be a lapse, the same pairs of [e] and the rest of the vowels have the same value.

Table 2				
<i>A 440 Hz - Decibel values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.</i>				
Filename	Segment	a1db	a2db	a3db
8va_1	i_la_440	62.5	56.8	44.0
8va_1	i_la_440	63.4	49.8	48.6
8va_1	u_la_440	64.2	51.8	49.3
8va_1	e_la_440	61.2	50.7	49.5
8va_1	e_la_440	68.4	57.4	54.6
8va_1	^_la_440	65.2	51.5	46.5
8va_1	a_la_440	66.9	55.0	53.0
a1db = Fundamental				
a2db = Overtone 1				
a3db = Overtone 2				

Table 2

Cardinal vowels - 440 hz



Graph 1. Cardinal vowels-440Hz. Values in decibels of fundamental, 1st overtone and 2nd overtone

In *Table 3*, there is similar information that was shown in *Graph 2*. All vowels have the same shape except one [i]. There is no real contrast. The high front vowel [e] and the lowest front vowel [æ] are together with a similar form. As mentioned above, the two tokens of [e] are covering most of the possible spectrum of the other vowels.

Table 3.

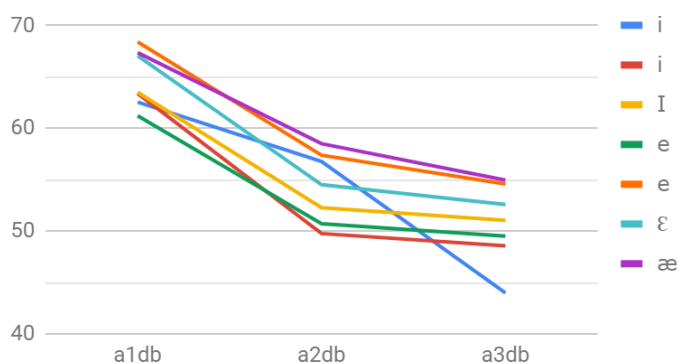
A 440 Hz - Decibel values in Fundamental, 1st overtone, and 2nd overtone of front vowels.

Filename	Segment	a1db	a2db	a3db
8va_1	i_la_440	62.5	56.8	44.0
8va_1	i_la_440	63.4	49.8	48.6
8va_1	l_la_440	63.5	52.3	51.1
8va_1	e_la_440	61.2	50.7	49.5
8va_1	e_la_440	68.4	57.4	54.6
8va_1	ɛ_la_440	67.0	54.5	52.6
8va_1	æ_la_440	67.3	58.5	55.0

a1db = Fundamental
a2db = Overtone 1
a3db = Overtone 2

Table 3

Front vowels - 440 Hz



Graph 2. Front vowels - 440Hz. Values in decibels of fundamental, 1st overtone and 2nd overtone.

4.2.2.2 Fundamental - A 880Hz

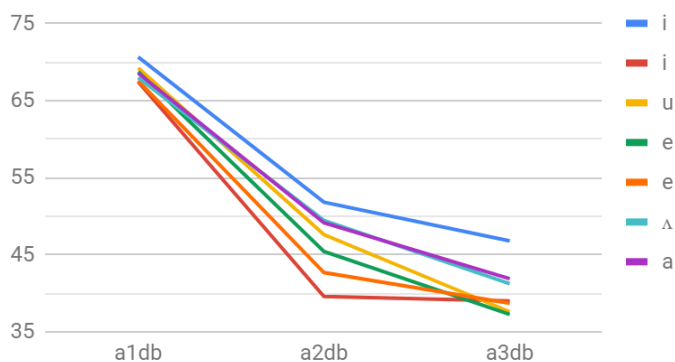
The second pitch to analyze is A 880Hz (second octave of the flute). *Graph 3* uses the information on *Table 4 - A 880Hz*; *Graph 4* take values of *Table 5 - A 880Hz*. The two tokens of [i] cover almost the whole possible spectrum of the other results, which eliminates any possible correlation between a front/back and high/low vowel. *Graph 4* shows the same results. In conclusion, there is no remarkable contrast, including cardinal vowels and front of vowels.

Table 4				
<i>A 880 Hz - Decibel values in fundamental, 1st overtone, and 2nd overtone of cardinal vowels.</i>				
Filename	Segment	a1db	a2db	a3db
8va_2	i_la_880	70.6	51.8	46.8
8va_2	i_la_880	67.4	39.6	39.0
8va_2	u_la_880	69.2	47.6	37.6
8va_2	e_la_880	68.7	45.4	37.3
8va_2	e_la_880	67.6	42.7	38.7
8va_2	^_la_880	68.0	49.4	41.3
8va_2	a_la_880	68.5	49.2	41.9

a1db = Fundamental
a2db = Overtone 1
a3db = Overtone 2

Table 4

Cardinal vowels - 880 Hz



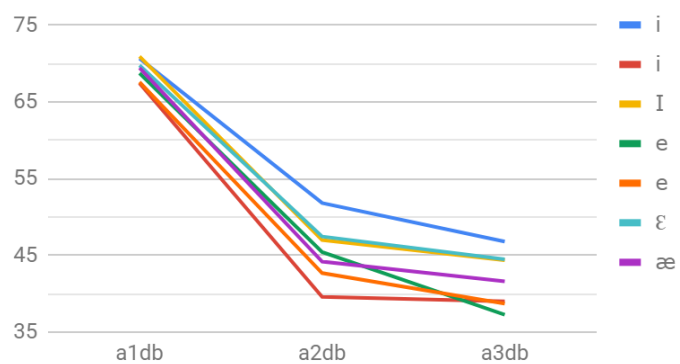
Graph 3. Cardinal vowels - 880Hz. Values in decibels of fundamental, 1st overtone and 2nd overtone.

Table 5				
A 880 Hz - Decibel values in Fundamental, 1st overtone, and 2nd overtone of front vowels.				
Filename	Segment	a1db	a2db	a3db
8va_2	i_la_880	70.6	51.8	46.8
8va_2	i_la_880	67.4	39.6	39.0
8va_2	l_la_880	70.9	4.0	44.4
8va_2	e_la_880	68.7	45.4	37.3
8va_2	e_la_880	67.6	42.7	38.7
8va_2	ɛ_la_880	69.7	47.5	44.5
8va_2	æ_la_880	69.4	44.2	41.6

a1db = Fundamental
a2db = Overtone 1
a3db = Overtone 2

Table 5

Front vowels - 880 Hz



Graph 4. Front vowels - 8800Hz. Values in decibels of fundamental, 1st overtone and 2nd overtone.

2.4.2.3 Fundamental - A 1760Hz

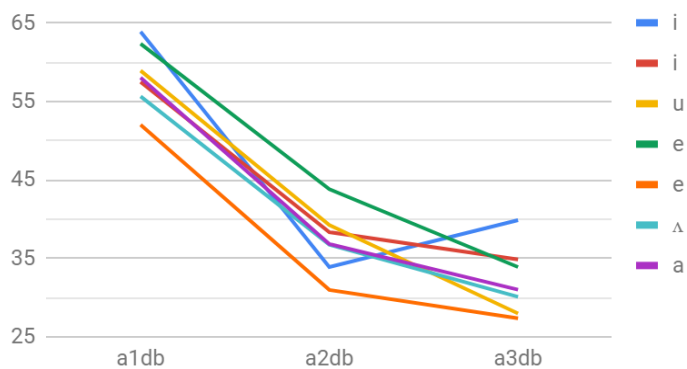
The third note to analyze is A 1760Hz (third octave of the flute). As in the previous two pitches, there is a similar shape in overtones. The two tokens of [e] cover any possible difference between another vowel. One token of [i] is slightly different, having a decline in the second overtone. However, that difference is not relevant. There is no significant contrast between cardinal vowels (*Table 6* and *Graph 5*) and front vowels (*Table 7* and *Graph 6*).

Table 6				
<i>A 1760 Hz - Decibel values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.</i>				
Filename	Segment	a1db	a2db	a3db
8va_3	i_la_1760	63.9	33.9	39.9
8va_3	i_la_1760	57.5	38.4	34.9
8va_3	u_la_1760	58.9	39.3	28.0
8va_3	e_la_1760	62.3	43.8	33.9
8va_3	e_la_1760	52.0	31.0	27.4
8va_3	ʌ_la_1760	55.6	36.8	30.1
8va_3	a_la_1760	58.0	36.9	31.0

a1db = Fundamental
a2db = Overtone 1
a3db = Overtone 2

Table 6

Cardinal vowels - 1760

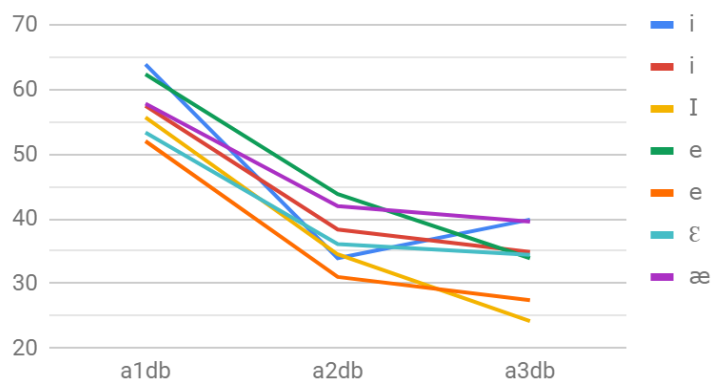


Graph 5. Cardinal vowels - 1760Hz. Values in decibels of fundamental, 1st overtone and 2nd overtone

Table 7				
A 1760 Hz - Decibel values in Fundamental, 1st overtone, and 2nd overtone of front vowels.				
Filename	Segment	a1db	a2db	a3db
8va_3	i_la_1760	63.9	33.9	39.9
8va_3	i_la_1760	57.5	38.4	34.9
8va_3	l_la_1760	55.7	34.5	24.2
8va_3	e_la_1760	62.3	43.8	33.9
8va_3	e_la_1760	52.0	31.0	27.4
8va_3	ɛ_la_1760	53.3	36.1	34.4
8va_3	æ_la_1760	57.8	42.0	39.6
a1db = Fundamental				
a2db = Overtone 1				
a3db = Overtone 2				

Table 7

Front vowels - 1760 Hz



Graph 6. Front vowels - 1760Hz. Values in decibels of fundamental, 1st overtone, and 2nd overtone.

2.4.3 Overall loudness

This section evaluates each note in decibels. Every pitch has its chart and graph. The table has seven columns: the first column shows the used vowels, followed by the solfège syllables and Hertz; the second column lines up the ranking of vowels, [i] and [u] being the highest and [a] and [æ] the lowest. The third column has the overall loudness of every vowel; it is the outcome of combining all overtones of the note in that vowel. This column of the graph illustrates overall loudness; the Y-axis shows intensity and the X-axis shows vowel intensity, as in column two of the chart.

The fourth column displays the difference between the fundamental and the first overtone, column five does the same but taking the distance between the first overtone and the second overtone. It is visually appreciable in the previous spectrum graphs, however, there is exact distance between them. Finally, column six measures the energy at the beginning of the note. Column seven does the same but at the end of it.

2.4.3.1 Fundamental - A 440Hz

In 440Hz, *Table 8* and *Graph 7* show that the lower vowels are louder than the high vowels, which could be argued. However, [e] (high vowel) is in both extremes (loud and quiet) which removes any support to the previous evidence. Intensity at the beginning and the end of the note seems to have random values, not corresponding to vowel height or backness.

Table 8

A - 440Hz Overall intensity index, distance between overtones, energy onset and end of the note.

Segment	Height	SumA1To3	A2-A1	A2-A3	AmpRise	AmpFall
i_la_440	5	163.3	5.8	12.8	5.7	-1.0
i_la_440	5	161.7	13.6	1.2	-5.7	-1.8
u_la_440	5	165.4	12.4	2.5	2.2	-2.0
l_la_440	4	166.8	11.2	1.2	2.6	-1.8
e_la_440	3	161.5	10.5	1.2	5.4	-0.4
e_la_440	3	180.3	11.0	2.8	-0.9	1.4
^_la_440	2	163.1	13.7	5.0	8.9	-5.1
ℰ_la_440	2	174.1	12.5	1.9	-3.7	-3.2
a_la_440	1	174.8	12.0	2.0	-1.8	-2.6
æ_la_440	1	180.8	8.8	3.5	-2.5	-0.9

SumA1to3 = Overall intensity index.

A2 - A1 = Distance between fundamental and 1st overtone.

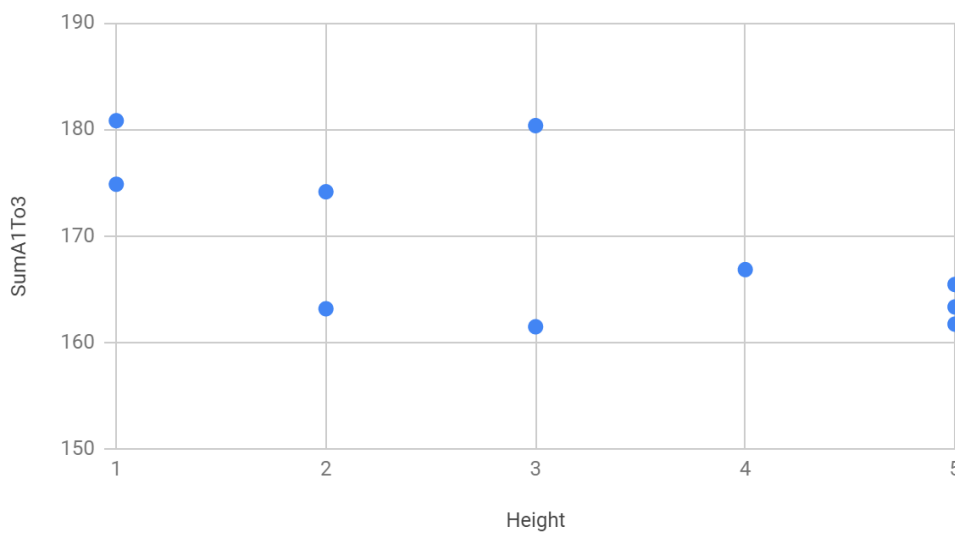
A2 - A3 = Distance between 1st overtone and 2nd overtone.

AmpRise= Energy at the beginning of the note.

AmpFall= Energy at the end of the note.

Table 8

SumA1To3 vs. Height



Graph 7. 440Hz Index of overall intensity. X-Axis decibels; Y-Axis vowel height.

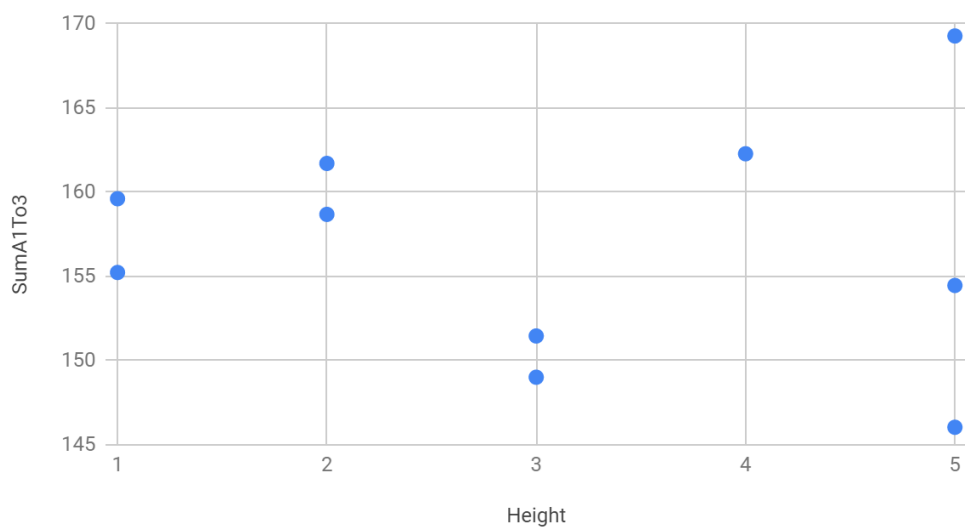
2.4.3.2 Fundamental - A 880Hz

In 880Hz, *Table 9* and *Graph 8* shows that the two tokens of the high vowel [i] cover the whole range of overall intensity of the other vowels; it is the loudest and quietest. It is hard to see any correlation. As in the previous pitch, the intensity at the beginning and at the end of the note seems to have random values, not corresponding to vowel height or backness.

Table 9						
<i>A - 880Hz Overall intensity index, distance between overtones, energy onset and end of the note.</i>						
Segment	Height	SumA1To3	A2-A1	A2-A3	AmpRise	AmpFall
i_la_880	5	169.3	18.8	5.0	-5.6	-3.8
i_la_880	5	146.0	27.8	0.6	-22.2	3.5
u_la_880	5	154.5	21.6	10.0	4.2	1.3
l_la_880	4	162.3	23.9	2.6	3.3	0.0
e_la_880	3	151.5	23.3	8.2	6.4	0.8
e_la_880	3	149.0	24.8	4.0	11.0	0.2
ʌ_la_880	2	158.7	18.5	8.2	-12	2.9
ɛ_la_880	2	161.7	22.3	3.0	0.6	5.7
a_la_880	1	159.6	19.4	7.2	-8.6	-10.6
æ_la_880	1	155.2	25.2	2.6	5.8	-3.3
SumA1to3 = Overall intensity index.						
A2 - A1 = Distance between fundamental and 1st overtone.						
A2 - A3 = Distance between 1st overtone and 2nd overtone.						
AmpRise= Energy at the beginning of the note.						
AmpFall= Energy at the end of the note.						

Table 9

SumA1To3 vs. Height



Graph 8. Overall loudness 880Hz. X-Axis decibels; Y-Axis vowel height.

2.4.3.3 Fundamental - A 1760Hz

This octave seems even more random than the previous results; there is no evident pattern. In *Table 10* and *Graph 9*, the same intensity is seen in tokens of high, mid, and low vowels.

Table 10

A - 1760Hz Overall intensity index, distance between overtones, energy onset and end of the note.

Vowel	Height	SumA1To3	A2-A1	A2-A3	AmpRise	AmpFall
i_la_1760	5	137.7	30.0	-6.0	-4.1	-10.6
i_la_1760	5	130.7	19.1	3.5	-2.2	8.5
u_la_1760	5	126.2	19.7	11.2	13.4	2.5
l_la_1760	4	114.4	21.2	10.3	15.7	-2.6
e_la_1760	3	140.1	18.5	9.9	1.4	14.4
e_la_1760	3	110.4	21.0	3.6	14.8	-4.1
^_la_1760	2	122.5	18.9	6.6	12.8	-4.6
ε_la_1760	2	123.8	17.2	1.6	9.9	3.2
a_la_1760	1	125.9	21.2	5.8	14.7	-0.4
æ_la_1760	1	139.4	15.9	2.4	4.4	6.5

SumA1to3 = Overall intensity index.

A2 - A1 = Distance between fundamental and 1st overtone.

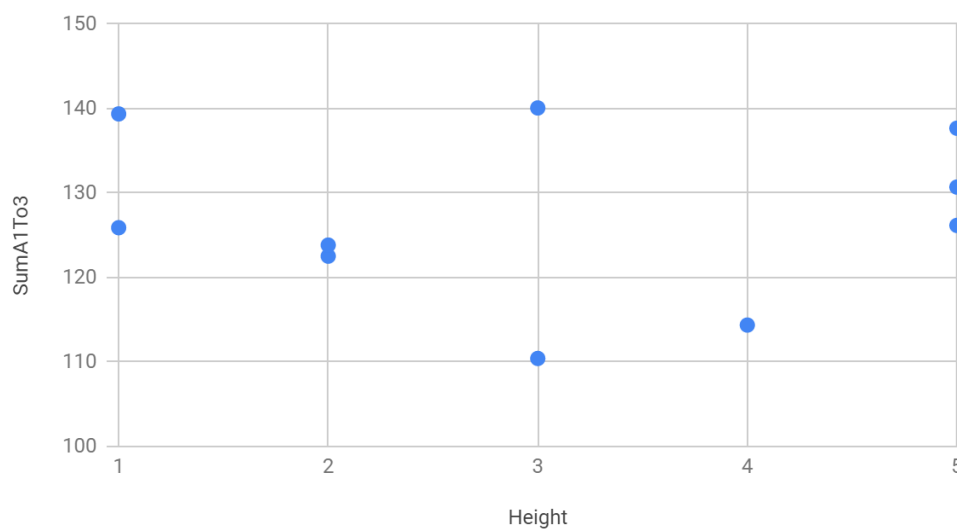
A2 - A3 = Distance between 1st overtone and 2nd overtone.

AmpRise= Energy at the beginning of the note.

AmpFall= Energy at the end of the note.

Table 10

SumA1To3 vs. Height

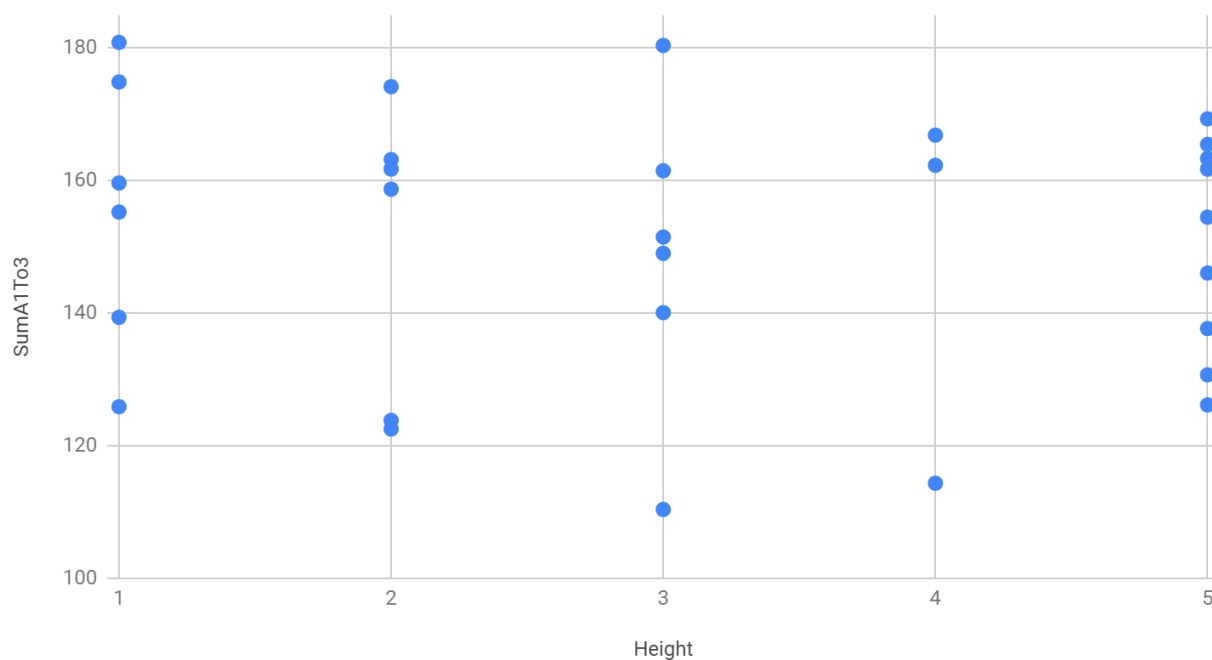


Graph 9. Overall loudness 1760Hz. X-Axis decibels; Y-Axis vowel height.

2.4.3.4 Combination of all vowels in all registers

Graph 10 is the result of combining *Graphs 7, 8, and 9*. It gives a global perspective of overall loudness and appears to show a random pattern within a range. A possible argument would be that low vowels are louder. However, it does not have a strong fundamental. Even assuming that the previous claim is valid, the change would be minimal and hard to predict because it varies drastically in the same vowel.

Energy in first 3 Harmonics



Graph 10. Overall loudness of all registers. X-Axis decibels; Y-Axis vowel height.

2.4.4 Specific spectral prominences

The specific spectral prominences take two frequencies, A 880Hz and A 1760Hz. Both have their chart and graph. Each spectrum is evaluated in two dimensions, as an overtone and as a fundamental. The lowest octave measured is 440Hz; its fundamental is 440Hz and its overtone is 880Hz. The middle octave measured is 880Hz; its fundamental is 880Hz. These two octaves are compared through 880Hz as an overtone and as a fundamental. The next octaves to be compared are the middle octave 880Hz and the highest octave 1760Hz. These octaves are compared through the overtone and fundamental 1760Hz. If there is any change in a vowel, this comparison should show it. Phonetic vowels differ significantly, especially in their second formant (first overtone). So, it is expected that the vowel shape would show different results modifying flute sound.

In *Tables 11 and 12*, the first column specifies the rank in height followed by the vowel; the second column shows the used vowel, followed by the solfège syllable; the third column presents the energy (in decibels) of the note as an overtone; and the fourth column shows the energy of the note as a fundamental. All measurements are taken at the onset of the note. *Graphs 11 and 12* represent the first overtone and the fundamental in decibels on the X-axis; on the Y-axis the value in decibels are measured. Notice that the values in the fundamental are higher than the values of 440Hz overtone. This phenomenon is common in voice and every instrument.

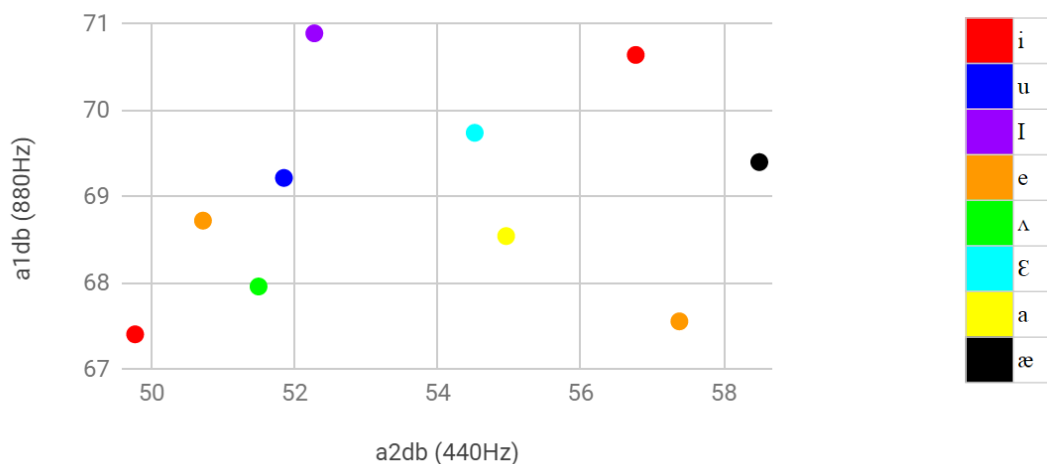
2.4.4.1 880Hz Specific spectral prominences

In 880Hz, the overtone of 440Hz covers a range of 8.7 decibels, which is shown in *Table 11* and *Graph 11*. The lowest vowel [æ] has the highest value, which contains one token. In contrast, one of the highest vowels [i] has the lowest value but contains two tokens. The two tokens of [i] encompass all the possible results in a range of 7 decibels in the first overtone at 440Hz, whereas the single token of [æ] is outside of this range by 2 decibels. [e] covers a range of 6.7 decibels, similar to the range of [i]. However, the distance of [e] is closer in proximity to the token of [æ] in 1.1 decibels. Overall, [i] and [e] are a major part of the possible results.

Table 11 <i>A - 880Hz Specific spectral prominences</i>		
Vowel	a2db	a1db
5-i	56.8	70.6
5-i	49.8	67.4
5-u	51.8	69.2
4-l	52.3	70.9
3-e	50.7	68.7
3-e	57.4	67.6
2-ʌ	51.5	68.0
2-ɛ	54.5	69.7
1-a	55.0	68.5
1-æ	58.5	69.4
a2db = 1st Overtone 440Hz a1db = Fundamental 880Hz Values in decibels Measured at the beginning of the note		

Table 11

a1db (880Hz) vs. a2db (440Hz)



Graph 11 Value in decibels of 440Hz first overtone and 880Hz fundamental.

2.4.4.2 1760Hz Specific spectral prominences

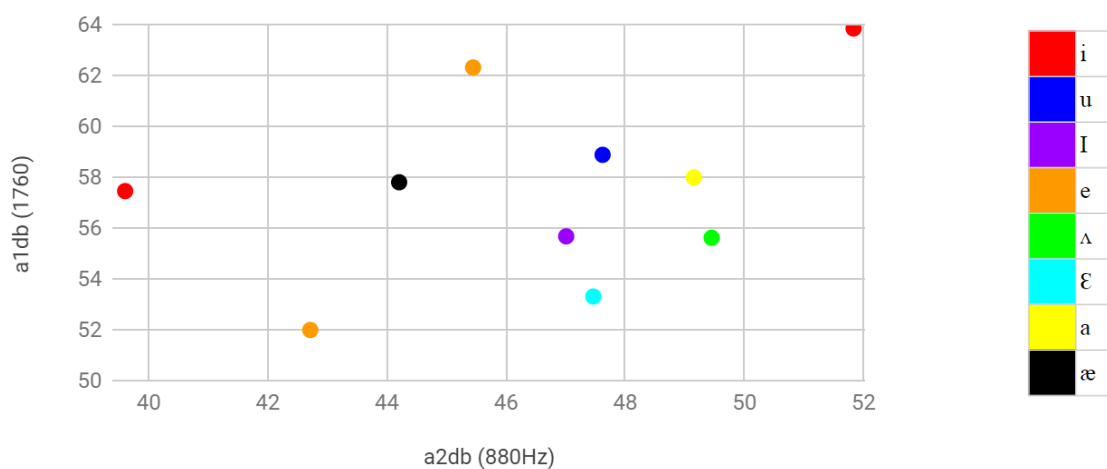
In 1760Hz, the overtone of 880Hz covers a range of 12.2 decibels. In *Table 12* and *Graph 12*, the highest value is [i] and the lowest value is [i]. In the fundamental 1760Hz, the highest value is one of the tokens of [i] and the lowest value is one of the tokens of [e], which are in the same area in a vowel phonetic perspective.

Table 12 A - 1760Hz Specific spectral prominences		
Vowel	a2db	a1db
5-i	51.8	63.9
5-i	39.6	57.5
5-u	47.6	58.9
4-l	47.0	55.7
3-e	45.4	62.3
3-e	42.7	52.0
2-ʌ	49.4	55.6
2-ɛ	47.5	53.3
1-a	49.2	58.0
1-æ	44.2	57.8

a2db = 1st Overtone 880Hz
a1db = Fundamental 1760Hz
Values in decibels.
Measured at the beginning of the note

Table 12

a1db (1760) vs. a2db (880Hz)



Graph 12. Value in decibels of 880Hz first overtone and 1760Hz fundamental.

CHAPTER III: DISCUSSION

3.1 Results: summary

After collecting the results and analyzing them individually, the measurements give us enough information to discuss in broad terms what happened in each part of the experiment and its analysis.

The main concern of this thesis is to discover any correlation between vowel shapes and flute sound. First, we consider the first three partials of the spectral analysis. All notes have the same form except two. The first different note is one token of [i] in the first octave of the flute. It still follows the same pattern, the fundamental being higher than the second one and the third one being lower. The second note is one token of [i] in the third octave, its second overtone is higher than the others, but it is 0.3 decibels away to [æ] (low vowel) which is contradictory if there were a vowel correlation.

Additionally, the difference is minimal, and the two tokens of the same vowel show the difference in those minimal changes. The results in this part of the experiment seem to support the claim that vowel shapes affect flute sound. If the argument were correct, each form would look different. Due to its spectral properties, it is expected that vowels having a high energy component in two notes would have the same quality, but the data shows different results.

In overall loudness, it seems that low vowels tend to sound louder in the first octave. Nevertheless, one token of [e] (high mid front vowel) is almost at the same level than the loudest pitch. The difference between [e] and [æ] is 0.5 decibels. Furthermore, one token of [e] is the

loudest, and the other token of [e] is the quietest with a range of 18.8 decibels. In the second octave, one token of [i] is the loudest and the softest, covering a range of 23.3 decibels. It is difficult to see any pattern, including the third octave and the combination of all notes. It seems that the data is forming random patterns inside a range of loudness, which is not directly connected with vowel quality.

The specific spectral prominences are a comparison between the same frequency as a fundamental and as an overtone. It presents some correlation between the two data sets, as the values share spectral properties. However, no evidence corresponds with the already known vowels. In the results, it is shown that the tokens of [i] cover a considerable portion of the possible outcomes of the other vowels, suggesting no systematicity. Nevertheless, some of the loudest components are high vowels.

In the tests, [u] does not show any notable difference from any other vowels. It is not at the extreme high or low end of the observed values. The results fail to demonstrate that vowel height make a significant difference. The front-back dimension, as the tongue body advances forward and the corona approximates the hard palate, also fails to demonstrate any notable change. [u] it is both back and rounded, and in contrast to most of the other vowels does not seem to have any systematic effect on loudness, spectral slope, or the strength of partials at any particular frequency.

Additionally, a statistical measurement was used to determine correlation. It determines if the values in the first variable (first overtone) are explained in the second variable (fundamental).

3.1.1 Measure correlation between series:

The Pearson Product-Moment Correlation Coefficient (PPMCC) was used to measure the strength of the linear relationship between the two variables. It gives a value on how closely related the two variables are.

The PPMCC is expected to give values between +1 and -1. +1 indicates total positive linear correlation, 0 is no linear correlation, and -1 suggests a negative linear correlation.

Variables

440Hz Overtone 1	880Hz Fundamental
------------------	-------------------

Pearson's value for 880Hz = 0.24

Variables

880Hz Overtone 1	1760Hz Fundamental
------------------	--------------------

Pearson's value for 1760Hz = 0.35

%VarianceExplained	0.12
--------------------	------

The statistical results show that there is a certain amount of variability in the values ranging from 6% - 12%. The rest is variability that we do not know, 88% – 94%. The percentage of variance is small, random, and not explained by the Theory of Vowels.

There are two levels in which the correlation results raise interesting questions. First, it needs to be determined whether a vowel articulation that reinforces a particular frequency on one occasion also tends to reinforce that frequency on other occasions. In the collected data, there is a small and variable tendency for correlation. The second question raised is whether the frequencies that different vowels appear to reinforce bear any systematic relationship to their

physical/acoustic properties, which does not seem to be true. It is not the case, for instance, that low vowels with F1 values near 880Hz reinforce that frequency more than high vowels with F1 values far away from 880Hz. Even if we accept that the tendency of particular vowel articulations to reinforce certain frequencies is 'real', the relationship must be governed by something other than the specific resonant frequencies of the vowels in question. According to the results, it is difficult to say what that relationship would be.

3.2 Conclusion

The evidence in this thesis fails to find a pattern of preliminary influences of vowel articulation on flute sound. The theory of vowels and acoustics more generally suggest that claims concerning vowel quality and flute timbre may not be correct; empirically, this exploratory study failed to find any systematic or obvious effects of vowel features on the acoustics of flute sounds. There is no gross difference in vowels; all shapes are overall the same, and there are no significant differences in loudness of different vowels. In conclusion, there is not a consistent pattern between back/round or front/unrounded vowels. If there is any change in high and low vowels, it would be minimal, and any consistent output would be complicated to obtain. The difference that we are considering is in decibels (loudness), not any change in timbre (color). That change in loudness could be obtained by playing with high volume without considering any vowel. Strictly judging from the results measured in this experiment, there was no detectable pattern in vowel articulations resonating with flute sound.

The topic of vowel shape could have a story similar to the myth of the diaphragm supporting the air column in singers and wind instruments. Both are topics that go beyond the

musicians' knowledge, and there could be misunderstandings. However, a flutist does not necessarily know about vowel acoustics or the physic-acoustics of the instrument. On the other hand, an expert flutist is not necessarily an expert physician, and their knowledge regarding the anatomy of the diaphragm could be limited. When two branches of knowledge meet, they can solve misunderstandings and clarify myths. Presently, we know that the saying "use your diaphragm to support the pitch" (Alt 1990) it is not true, and took decades to comprehend. The efforts to improve the field and discover what is behind the myth comes from curiosity and questioning the patterns that have already been established. This thesis strives to encourage interdisciplinary studies challenging those pattern and exploring other perspectives. Here, the field of linguistics is clarifying that it is unlikely to change the color of the flute by shaping vowels in the mouth.

Because singing is one of the first expressions of music, flutists often try to imitate singing while playing. There are multiple teachings that reinforce the concept that singing and playing the flute are similar, such as support of air flow, vibrato, expression, connecting and shaping phrasing. Those concepts are supported by qualified musicians, which leads to widespread belief that singing and flute playing are closely related. Professional musicians are often motivated to explore all possible sounds and techniques of an instrument. By doing this, musicians create different ideas to modify sound and expand an instrument's possibilities. Through this exploration, false ideas could spread and are considered facts even though they have not been proven. Overall, these issues contributed to the false belief that vowel articulations can modify the timbre of a flute according to the data collected in this experiment. However, if a

wider range of data were gathered in this experiment, different patterns could be detected, which would cause overall conclusions to change.

3.3 Pedagogical implications

There is literature and commentary from different flutists supporting a theory where vowel shapes make music more interesting; some instructors suggest practicing vowels to expand the possible interpretative skills of the students. Based on the results of this study, there is no substantial evidence to support that claim. Instead, students should concentrate their time and energy on overcoming other difficulties on the flute. If there is any vowel preference, that decision will come from a subjective basis of the performer, for instance giving a comfortable feeling playing, sounding better to the flutist, or matching with that particular instrument. Those claims would change depending on individual perception, not scientific fact. Additionally, there could be a claim stating that a minimal change would affect the music. However, from the data that we have, that minimal difference is difficult to predict. If there is a concrete recommendation for flutists, it would be to allow the air to go through and reduce any unnecessary resistance in the jetstream of air.

3.4 Pilot perception study

In spring 2018, the author, an experienced flutist with a graduate degree, conducted a pilot study. The goal of the study was to determine if participants can audibly distinguish between different vowel articulations in a flute. The author recorded the samples; no voicing of vowels or vibrato were used. The shape inside the mouth was the only differentiating factor when

comparing the recordings. The cardinal vowels [a], [i], and [u] were recorded in one pitch, A=440Hz. Five musicians with nine to twenty years of experience in music and one without experience took the survey. Two of the musicians were flutists. The survey asked for their instrument, years of experience in music, and five tests of vowel distinction. Three of the tests asked to identify each cardinal vowel in isolation. The other two tests challenged the participants to identify the order of vowel articulations in series of three (eg. [i], [a], [u] and [a], [i], [u]). Although, participants could hear the recording as many times as they wanted, they answered correctly less than half of the time; of 25 total answers, only 5 were correct. For [i] there were no correct answers, for [u] 60% of the answers were correct, and [a] 20% of the answers were correct. In the series of three vowel articulations [i], [a], [u] there were 20% correct answers and in the series of [a], [i], [u] there were no correct answers. Results and questions can be found in the appendix.

3.5 Future studies

A subsequent researcher can replicate this work of analysis and perception using more data from different flutists, preferably performers who believe vowel shapes change the timbre of the instrument. In this acoustic analysis, one experienced flutist was recorded and in the pilot perceptual study, one flutist was recorded and five participants took the survey. The results in these two studies contradict other researchers' results as well as years of conventional knowledge of colleagues and famous flutists, and it would be valuable to perform these experiments on a larger scale despite the present evidence suggesting no correlation. In future auditory tests, it

would be beneficial to create general questions that ask participants if they can detect any differences in sound production, which would be simpler than the hearing test in the pilot study.

The next step for this research is to investigate consonants in flute sounds. Future research would investigate how consonants in flute sound work physically, acoustically, and any implication in the relationship between consonants and vowels. Although every mouth is different and every flutist is a whole universe, a study of this kind would yield generalizations and suggestions.

Although this study failed to find a consistent pattern regarding vowel articulations, there are many variables that determine the individual characteristics of flute sound. In the future, it would be beneficial to explore which characteristics contribute to the unique production of sound in a flute. After identifying the major contributing factors, it would allow the specific variables that influence the sound variation to be measured and analyzed.

APPENDIX

Appendix 1												
A 440 Hz - Decibel values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.												
Segment label	Note onset			Middle of the note			End of the note					
	a1db	a2db	a3db	a1db	a2db	a3db	a1db	a2db	a3db			
i_la_440hz	62.53907703	56.76902277	44.00810533	62.0000126	58.41817589	48.61513647	62.22706273	57.37621778	50.41884392			
i_la_440hz	63.36506337	49.76900171	48.56804587	62.21492583	48.71074389	45.09257711	61.29443541	53.05652885	43.48929728			
e_la_440hz	61.21850809	50.71787834	49.51816956	61.57213295	53.77485036	51.46244773	60.81380504	56.10089434	50.24882882			
e_la_440hz	68.3815027	57.37920992	54.58034453	66.76299061	59.98136904	52.73964787	65.50034936	60.42682153	52.10919565			
l_la_440hz	63.48738243	52.27503444	51.06072806	63.81190845	56.36084456	49.23398376	63.98250459	56.26955564	51.00061899			
u_la_440hz	64.24782823	51.8496308	49.32638767	64.98260446	50.0493204	52.54984772	65.67652105	51.10048842	52.84402093			
ʌ_la_440hz	65.15562189	51.4950203	46.49489667	65.89924615	57.05422525	49.10492708	65.48646165	60.09998228	51.58655233			
ɛ_la_440hz	67.02769216	54.51741314	52.58626481	64.96226482	54.66495073	50.80219081	66.31144644	54.8367002	52.49066781			
a_la_440hz	66.91434169	54.95686848	52.96613295	65.8447242	55.7976192	51.38132243	65.5084869	56.65855676	53.46746652			
æ_la_440hz	67.34363079	58.49701486	54.96293237	65.86643608	59.73384417	52.74801457	65.74686069	60.37212821	53.1619085			

a1db = Fundamental
a2db = Overtone 1
a3db = Overtone 2

Appendix 2												
A 440 Hz - Herz values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.												
Segment label	Note onset			Middle of the note			End of the note					
	a1db	a2db	a3db	a1db	a2db	a3db	a1db	a2db	a3db			
i_la_440hz	441.40625	881.8359375	1323.242188	441.40625	881.8359375	1323.242188	441.40625	882.8125	1325.195313			
i_la_440hz	441.40625	882.8125	1325.195313	441.40625	882.8125	1324.21875	442.3828125	883.7890625	1326.171875			
e_la_440hz	438.4765625	876.953125	1315.429688	438.4765625	877.9296875	1316.40625	438.4765625	877.9296875	1317.382813			
e_la_440hz	443.359375	886.71875	1330.078125	443.359375	886.71875	1330.078125	443.359375	887.6953125	1331.054688			
l_la_440hz	441.40625	883.7890625	1325.195313	442.3828125	884.765625	1327.148438	443.359375	886.71875	1329.101563			
u_la_440hz	436.5234375	872.0703125	1308.59375	438.4765625	876.953125	1314.453125	439.453125	878.90625	1318.359375			
ʌ_la_440hz	437.5	874.0234375	1311.523438	436.5234375	873.046875	1309.570313	438.4765625	875.9765625	1314.453125			
ɛ_la_440hz	442.3828125	884.765625	1327.148438	442.3828125	883.7890625	1326.171875	443.359375	885.7421875	1329.101563			
a_la_440hz	441.40625	882.8125	1324.21875	440.4296875	880.859375	1321.289063	440.4296875	881.8359375	1322.265625			
æ_la_440hz	443.359375	886.71875	1329.101563	443.359375	887.6953125	1331.054688	444.3359375	887.6953125	1332.03125			
a1db = Fundamental												
a2db = Overtone 1												
a3db = Overtone 2												

Appendix 3												
A 880 Hz - Decibels values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.												
Segment label	Note onset			Middle of the note			End of the note					
	a1db	a2db	a3db	a1db	a2db	a3db	a1db	a2db	a3db			
i_la_880hz	70.64106418	51.83217894	46.80350246	70.09886585	48.27639879	45.31031039	69.55754312	51.40625582	46.48310132			
i_la_880hz	67.4047144	39.60474375	39.03219874	67.57329782	16.43864495	39.86188062	68.20315851	10.453372	41.74831327			
e_la_880hz	68.72158502	45.44612505	37.29421822	70.23789415	48.00914745	39.6348689	70.3114965	47.17944398	39.60010028			
e_la_880hz	67.55468368	42.71273228	38.74529465	69.96974914	47.29791357	42.72837669	69.68933018	46.70758316	43.35680617			
u_la_880hz	70.8916279	47.0085147	44.38112969	70.60774838	49.39464678	45.62201531	70.95349763	48.67405179	45.99339147			
u_la_880hz	69.21637589	47.61956461	37.62637933	70.30082899	46.46736332	41.85271651	69.97626084	44.72303641	42.65807701			
A_la_880hz	67.95890559	49.44992274	41.27359589	67.10484699	40.53913606	39.01644854	68.15410085	40.66874015	34.93603511			
E_la_880hz	69.73901305	47.4635494	44.50573861	70.56563461	46.79506845	44.91905175	70.75058564	45.5051901	40.33952568			
a_la_880hz	68.54291409	49.15226401	41.91803407	68.46458691	44.02625131	38.50845203	69.28931918	50.18670671	42.11522821			
æ_la_880hz	69.39973418	44.20437118	41.62914236	69.76792089	48.45123217	42.8568868	70.04107325	49.77341981	44.56857295			
a1db = Fundamental												
a2db = Overtone 1												
a3db = Overtone 2												

Appendix 4												
A 880 Hz - Herz values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.												
Segment label	Note onset			Middle of the note			End of the note					
	a1db	a2db	a3db	a1db	a2db	a3db	a1db	a2db	a3db			
i_la_880hz	883.7890625	1767.578125	2651.367188	883.7890625	1767.578125	2650.390625	883.7890625	1768.554688	2652.34375			
i_la_880hz	882.3242188	1764.648438	2646.972656	883.7890625	1321.289063	2653.320313	885.2539063	1332.03125	2655.273438			
e_la_880hz	877.9296875	1755.859375	2633.789063	877.9296875	1755.859375	2632.8125	877.9296875	1755.859375	2633.789063			
e_la_880hz	887.6953125	1772.460938	2660.15625	883.3007813	1766.601563	2649.902344	883.7890625	1767.578125	2650.878906			
l_la_880hz	886.71875	1773.4375	2661.132813	884.765625	1770.507813	2655.273438	884.765625	1769.53125	2654.296875			
u_la_880hz	876.953125	1754.882813	2631.835938	876.953125	1753.90625	2629.882813	875	1750.976563	2625.976563			
Λ_la_880hz	881.8359375	1764.160156	2645.996094	881.8359375	1763.671875	2645.996094	878.4179688	1756.347656	2634.277344			
ɛ_la_880hz	887.2070313	1773.4375	2660.644531	887.6953125	1774.902344	2662.109375	887.6953125	1775.390625	2663.085938			
a_la_880hz	884.2773438	1768.554688	2652.832031	880.3710938	1760.742188	2640.625	881.8359375	1763.183594	2645.019531			
æ_la_880hz	887.6953125	1775.390625	2663.085938	886.2304688	1772.460938	2659.179688	885.7421875	1770.996094	2656.738281			

a1db = Fundamental
a2db = Overtone 1
a3db = Overtone 2

Appendix 5												
A 1760 Hz - Decibels values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.												
Segment label	Note onset			Middle of the note			End of the note					
	a1db	a2db	a3db	a1db	a2db	a3db	a1db	a2db	a3db			
i_la_1760	63.8786711	33.91337203	39.88037773	63.72409692	33.23772281	36.5630184	65.79215668	41.77544275	36.54911388			
i_la_1760	57.47771696	38.35008904	34.8772367	58.75733521	37.72455363	32.03497976	57.06929302	33.35085168	29.60329711			
e_la_1760	62.34372903	43.81761903	33.91314991	65.42708103	38.8655768	37.15766963	63.32329582	32.14443499	31.59363772			
e_la_1760	52.01138868	31.00592357	27.39951233	57.25228707	34.18436147	33.74291045	56.54677294	37.26848418	35.50133986			
l_la_1760	55.6967743	34.50018196	24.17101027	61.0224769	39.74494622	29.3088487	61.49568256	40.21206439	30.93171098			
u_la_1760	58.90606098	39.25496633	28.00677284	63.67231308	42.1569341	33.70031317	63.22558031	40.01490626	33.78398993			
ʌ_la_1760	55.64180622	36.76346983	30.12443472	61.67686357	40.96645681	32.67101297	64.06164281	41.51032324	34.37623042			
ɛ_la_1760	53.32840388	36.07872463	34.42906491	59.54164713	38.03115787	36.12045583	59.39771829	35.35735176	35.78577446			
a_la_1760	58.01561026	36.85099091	31.02997957	63.21832876	40.84307889	36.53998888	61.99659995	42.33887007	36.68448727			
æ_la_1760	57.82519286	41.96704276	39.57753194	60.21739511	45.08806901	38.49448833	60.11161236	41.3306799	35.89925933			
a1db = Fundamental												
a2db = Overtone 1												
a3db = Overtone 2												

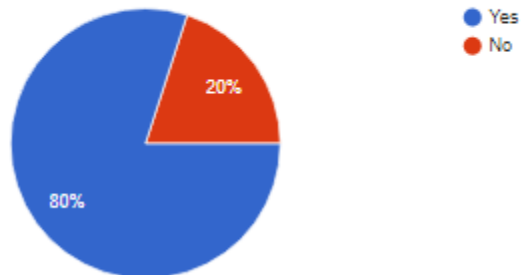
Appendix 6												
A 1760 Hz - Herz values in Fundamental, 1st overtone, and 2nd overtone of cardinal vowels.												
Segment label	Note onset			Middle of the note			End of the note					
	a1db	a2db	a3db	a1db	a2db	a3db	a1db	a2db	a3db			
i_la_1760	1768.554688	3537.109375	5304.6875	1763.671875	3526.367188	5289.0625	1764.648438	3530.273438	5294.921875			
i_la_1760	1770.019531	3540.039063	5310.058594	1768.066406	3536.621094	5304.199219	1768.066406	3536.621094	5304.6875			
e_la_1760	1770.507813	3541.992188	5312.5	1766.601563	3533.203125	5299.804688	1768.554688	3535.15625	5302.734375			
e_la_1760	1776.367188	3552.246094	5329.101563	1772.949219	3546.386719	5319.824219	1773.925781	3548.339844	5322.753906			
l_la_1760	1770.996094	3541.503906	5311.035156	1766.601563	3532.714844	5301.269531	1765.625	3531.25	5296.875			
u_la_1760	1768.066406	3535.644531	5301.757813	1764.160156	3528.320313	5292.96875	1764.160156	3528.320313	5292.480469			
Λ_la_1760	1770.019531	3542.480469	5314.453125	1765.136719	3529.785156	5294.921875	1764.648438	3528.808594	5293.457031			
ɛ_la_1760	1775.878906	3553.222656	5329.589844	1772.460938	3544.921875	5317.382813	1770.996094	3542.480469	5313.964844			
a_la_1760	1770.996094	3541.503906	5312.011719	1768.066406	3535.644531	5303.710938	1768.066406	3535.644531	5303.710938			
æ_la_1760	1778.808594	3558.105469	5337.402344	1780.273438	3560.546875	5340.820313	1777.832031	3556.640625	5334.960938			
a1db = Fundamental												
a2db = Overtone 1												
a3db = Overtone 2												

Pilot perception study

Results:

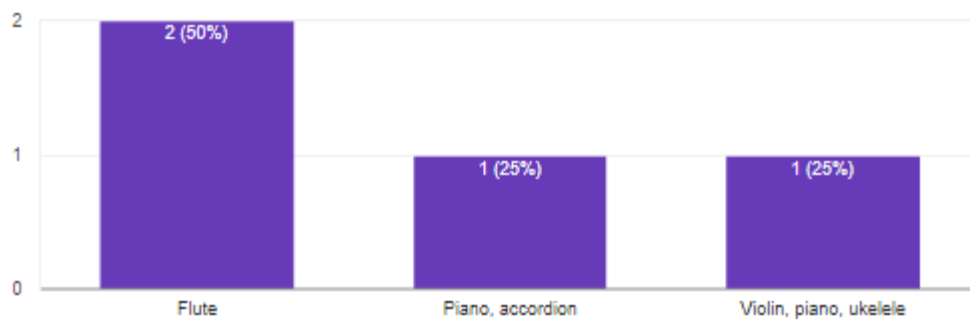
Are you a musician?

5 responses



If yes, which instrument or instruments do you play?

4 responses



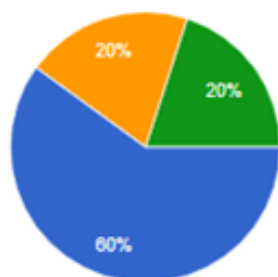
How long have you been playing your principal instrument?

4 responses

20 years
9 years
15 years
10 years

Correct answer: [i]

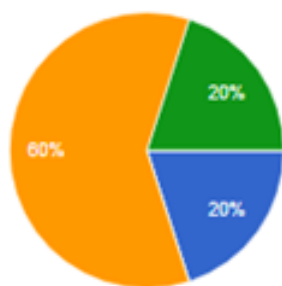
5 responses



- [a] as "father"
- [i] as "hid"
- [u] as "food"
- He is playing different vowels
- I do not know the answer

Correct answer: [u]

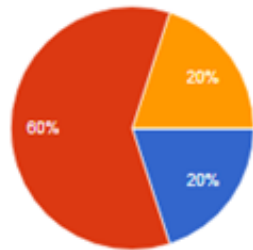
5 responses



- [a] as "father"
- [i] as "hid"
- [u] as "food"
- He is playing different vowels
- I do not know the answer

Correct answer: [a]

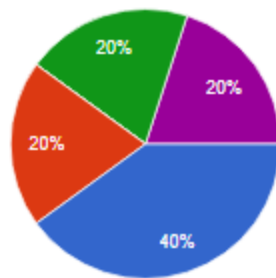
5 responses



- [a] as "father"
- [i] as "hid"
- [u] as "food"
- He is playing different vowels
- I do not know the answer

Correct answer: [i] [a] [u].

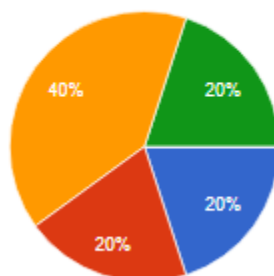
5 responses



- [a] [i] [u]
- [i] [a] [u]
- [i] [u] [a]
- [u] [a] [i]
- I do not know the answer

Correct answer: [a] [i] [u]

5 responses



- [a] [i] [u]
- [i] [a] [u]
- [i] [u] [a]
- [u] [a] [i]
- I do not know the answer

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