

Clarinet Multiphonics: A Catalog and Analysis of Their Production Strategies

by

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ABSTRACT

Clarinet multiphonics have become increasingly popular among composers since they were first introduced in the 1950s. However, it is a topic poorly understood by both performers and composers, which sometimes leads to the use of acoustically impossible multiphonics in compositions. Producing multiphonics requires precise manipulations of embouchure force, air pressure, and tongue position. These three factors are invisible to the naked eye during clarinet performance, leading to many conflicting theories about multiphonic production strategies, often based on subjective perception of the performer. This study attempts to observe the latter factor—tongue motion—during multiphonic production in situ using ultrasound. Additionally, a multiphonic catalog containing 604 dyad multiphonics was compiled as part of this study. The author hypothesized that nearly all, if not all, of the multiphonics can be produced using one of four primary production strategies. The four production strategies are: (A) lowering the back of the tongue while sustaining the upper note; (B) raising the back of the tongue while sustaining the upper note; (C) changing the tongue position to that of the lower note while sustaining the upper note; and (D) raising the root of the tongue (a sensation similar to constricting the throat) while sustaining the upper note. To distill production strategies into four primary categories, the author documented his perceived tongue motion over twenty repetitions of playing every multiphonic in the catalog. These perceptions were then confirmed or corrected through ultrasound investigation sessions after every five repetitions. The production strategies detailed in this study are only for finding the correct voicing to produce the multiphonics. The catalog compiled during this study is organized using two different organizational systems: the first uses the traditional method of

organizing by pitch; the second uses a fingering-based system to facilitate the ease of finding multiphonics in question, since notated pitches of multiphonics often differ between sources.

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CHAPTER 1

INTRODUCTION

Since the middle of the 20th century, extended techniques have become increasingly popular compositional tools. One notable extended technique for the clarinet is multiphonics. However, from both compositional and performance perspectives, multiphonics are often misunderstood due to limited and outdated resources available on the subject. *New Directions for the Clarinet* by Phillip Rehfeldt is the most recent published resource for soprano clarinet multiphonics. The most recent revised edition of *New Directions* was published in 1994 and is still an excellent resource for composers, though performance instruction is limited. From the performance perspective, a major obstacle is the reliance on subjective perception of the physiological mechanisms involved in performance, especially the role of the tongue. The author noticed when encountering multiphonics in repertoire that the correct manipulation of the tongue seemed critical to successfully producing multiphonics, and many multiphonics require the tongue to form specific shapes and move in ways that are uncharacteristic of conventional clarinet performance. Since the tongue is invisible to the naked eye during performance and subjective perceptions can be unreliable, it is difficult to gain a detailed understanding and have an informed discussion of the tongue's role during multiphonic production.

The current study attempts to objectively observe the tongue shapes used to produce multiphonics using ultrasound imaging. Previous studies have used ultrasound

imaging to examine articulatory tongue motion during clarinet performance.¹ The present study adapted the same protocol to examine a non-articulatory tongue motion—multiphonic production. A catalog of dyad multiphonics with performance instructions for each multiphonic was compiled based on the study results. The goals of this study are to improve existing multiphonic pedagogy and make multiphonics less perplexing and more accessible to performers and composers.

¹ Joshua T. Gardner, “Ultrasonic Investigation of Clarinet Multiple Articulation,” (DMA diss., Arizona State University, 2010).

CHAPTER 2

HISTORY OF CLARINET MULTIPHONICS

Multiphonic tone production is an extended technique first introduced to the clarinet in the mid 1900s. Antonio Ferrannini was the first to describe in writing the phenomenon of simultaneously producing more than one pitch on the clarinet.² Rehfeldt mentions the use of multiphonics in jazz performances, mostly by bass clarinetist Eric Dolphy, though the multiphonics were used during improvisations and were not notated in music scores.³ The first detailed description (in English) of multiphonics was in Bruno Bartolozzi's *New Sounds for Woodwinds*, published in 1967. Bartolozzi described multiphonics as “the generation, at one and the same time, of a number of frequency vibrations in the single air column of an instrument.”⁴ This is also the definition that the present study will adopt, thereby excluding sounds produced by singing and playing simultaneously.

In early documentation of multiphonics, various terms were used to describe the phenomenon of simultaneously producing more than one note on the clarinet. Two terms still commonly in use today, often interchangeably with multiphonics, are *multiple sonorities* and *multiple sounds*. Other terms used describe multiphonics include polyphonics, chords, double stops, overtones, and harmonics. Many of these terms are inappropriate for describing multiphonics; however, the terminology can provide insight and help track the development of multiphonics throughout the years. *Polyphonic*,

² Phillip Rehfeldt, *New Directions for the Clarinet*, rev. ed. (Lanham, MD: Scarecrow Press, 2003), 41.

³ Ibid.

⁴ Bruno Bartolozzi, *New Sounds for Woodwind*, ed. and trans. Reginald Smith Brindle (London: Oxford University Press, 1967), 35.

derived from the word *polyphony*, is defined by The Oxford Dictionary of Music as “music in which several simultaneous instrumental parts are combined contrapuntally”⁵ rather than the simultaneous production of multiple pitches on a traditionally single pitched instrument. Multiphonics may be written *polyphonically*, in that the two voices act as distinct musical lines; however, that is not always the case. *Chords* are defined by The Oxford Dictionary of Music as “any simultaneous combination of notes, but usually of not fewer than 3.”⁶ Although this definition is correct in describing multiphonics, using the term *chords* suggests that the composer or performer has a choice of which notes are produced. However, the pitches of multiphonics are determined by the acoustics of the instrument rather than by the composer or performer. *Double stop* is a term for a technique common on string instruments where two strings—two separate sound generating mechanisms—are played simultaneously. While two or more pitches are produced simultaneously when performing multiphonics, two standing waves are created within the same vibrating air column, offering a unique distinction between them and the double stops on a string instrument. *Overtones* and *harmonics* are terms describing monophonic pitches derived from the harmonic series of another pitch rather than the simultaneous production of multiple pitches.

Bruno Bartolozzi noted in *New Sounds for Woodwind* that multiphonics are almost exclusive to the woodwind family. It is important to note that Bartolozzi’s book addresses only flute, oboe, clarinet, and bassoon when referring to the woodwind family.

At the time the book was published, the only non-woodwind instrument supposedly

⁵ Tim Rutherford-Johnson, Michael Kennedy, and Joyce Bourne Kennedy, eds., *The Oxford Dictionary of Music*, 6th ed. (Oxford University Press Online, 2013) accessed April 2, 2018, <http://www.oxfordreference.com>.

⁶ Ibid.

capable of producing multiphonics was the trombone.⁷ Furthermore, Bartolozzi also mentioned that, at the time his book was written, the clarinet was the only instrument capable of producing multiphonics with any given fingering. Other instruments in the woodwind family have fingerings that will produce only single pitches, regardless of how the physiological sound production mechanisms are manipulated.⁸ However, it is possible that woodwind players today have discovered methods to produce multiphonics using fingerings not previously identified as producing multiphonics. Due to this unique property of the clarinet, it is capable of producing a much larger quantity of unique multiphonics than other woodwinds. With the increased sonic possibilities, composers may be more inclined to experiment with multiphonics in their compositions for clarinet than in their compositions for other instruments. Bartolozzi states that each multiphonic is generated when specific technical conditions of sound production are met. The technical conditions are achieved by distorting or altering embouchure, lip pressure, and air pressure.⁹ Beyond these general explanations, no further information about specific distortion or alteration needed to achieve the conditions of sound production was provided.

Another important figure in the development of clarinet multiphonics is composer and performer William O. Smith. In 1959, Smith was inspired to experiment with the possibilities of clarinet multiphonics after hearing Severino Gazzeloni perform Berio's *Sequenza I* for flute, in which a dyad multiphonic was used.¹⁰ One of Smith's most

⁷ Ibid., 36.

⁸ Ibid., 37.

⁹ Ibid., 38

¹⁰ Rehfeldt, *New Directions*, 99.

notable contributions is his documentation of every multiphonic fingering he discovered, along with its sonic properties.¹¹ Smith received the Guggenheim Fellowship and spent a year in Europe furthering his research. While there, Smith systematically tested multiphonic possibilities of every clarinet fingering combination he could conceive. While experimenting, Smith documented the pitches, timbre, possible dynamic levels, and ease of production of each multiphonic on index cards. These index cards provided the clarinet community with one of the first extensive multiphonic fingering catalogs. Smith also collaborated with composer John Eaton to produce the first composition in which multiphonics were used in a controlled manner. Eaton's *Concert Music for Solo Clarinet* was composed for Smith to perform at a series of concerts at festivals in Europe and was conceived specifically to demonstrate the newly explored technique of playing multiphonics on the clarinet.¹²

After the initial experimentation of multiphonic possibilities by composers and performers such as Bartolozzi and Smith in early 1950s, other well-known and established composers such as Luciano Berio, Pierre Boulez, and Karlheinz Stockhausen began to use multiphonics in their clarinet compositions. Other North American composers who used clarinet multiphonics in their compositions not long after Smith include Elliot Carter, Ronald Caravan, Gerard Errante, and Eric Mandat.

In the late 1900s and early 2000s, multiphonics and other extended techniques became popular academic topics. Resource books such as those by Bartolozzi, Farmer, and Rehfeldt were published addressing various extended techniques, including

¹¹ Ibid., 100-120.

¹² John E. Anderson, "An Analytical and Interpretive Study and Performance of Three Twentieth-century Works for Unaccompanied Clarinet," (Ed.D diss. Columbia University, 1974), 68, 180.

multiphonic production.¹³ Additionally, numerous dissertations, etude books, and articles were written on multiphonics, such as those by Caravan and Mandat.¹⁴ Interestingly, very few resources concerning multiphonics have been published in the past decade. The most commonly consulted resource today is Rehfeldt's book—over 20 years after it was published. Two notable recent publications include *Spectral Immersions: A Comprehensive Guide to the Theory and Practice of Bass Clarinet Multiphonics* by Sarah Watts, and *The Bass Clarinet: A Personal History* by Harry Sparnaay. However, these books limit their scope to bass clarinet multiphonics; B-flat soprano clarinet multiphonics are not addressed at all. This omission could be due to a recent increased interest in writing for bass clarinet in contemporary music.¹⁵ Many composers have been attracted to the versatility of the bass clarinet. It has a larger effective range, and certain techniques such as slap tonguing are more effective compared to the same techniques used on soprano clarinets.¹⁶ Another reason could be the transition into the digital media age, with the availability of several online resources for clarinet multiphonics, though online information is not nearly as extensive as the published books for bass clarinet.

Despite the increased use of multiphonics in compositions in the late 20th century and early 21st century, the possibilities and limitations of multiphonics have yet to become common knowledge among both composers and performers. There are

¹³ Bartolozzi, *New Sounds for Woodwind*; Gerald Farmer, *Multiphonics and Other Contemporary Clarinet Techniques*, (Rochester, N.Y.: SHALL-u-mo, 1982); Rehfeldt, *New Directions*.

¹⁴ Ronald Caravan, "Extensions of Technique for Clarinet and Saxophone," (DMA diss., University of Oregon, 1989); Ronald Caravan, *Preliminary Exercises and Etudes in Contemporary Techniques for Clarinet: Introductory Material for the Study of Multiphonics, Quarter Tones, and Timbre Variation*. N.p.: Ethos Publications, 1979; Eric Mandat, "Expanding Timbral Flexibility through Multiphonics," *The Clarinet* 16, no. 3 (July-August 1989): 27-30.

¹⁵ Harry Sparnaay, *The Bass Clarinet: A Personal History*, 3rd ed., trans. Annelie de Man and Paul Roe (Barcelona, Spain: Periferia Sheet Music, 2012), 165.

¹⁶ *Ibid.*, 53, 65.

composers today, especially student composers, who are misinformed by outdated or inaccurate resources, resulting in compositions utilizing multiphonics with impossible or unrealistic expectations of pitches or timbre.¹⁷ Alternatively, the composer may leave the choice of multiphonic up to the performer, with no indication of desired pitch or timbre.¹⁸ Some composers have mentioned in interviews conducted by Watts that they avoid writing multiphonics completely, not because they do not want to, but because they cannot find resources to help them understand multiphonics.¹⁹ Additionally, a consulted performer may not be able to provide specific information or may unintentionally misinform composers regarding multiphonics, perhaps due to a lack of exposure and/or experience. Some performers, through no fault of their own, may not encounter multiphonics at all throughout their entire professional training. Watts noted several times throughout her book that composers who collaborated with performers were often more successful in incorporating multiphonics into their compositions.

¹⁷ Sarah Watts, *Spectral Immersions: A Comprehensive Guide to the Theory and Practice of Bass Clarinet Multiphonics* (n.p.: Metropolis Music Publishers, 2015), 29.

¹⁸ Ibid., 11.

¹⁹ Ibid., 1, 22.

CHAPTER 3

ACOUSTICS OF MULTIPHONICS

While a detailed account of clarinet acoustics is beyond the scope of this paper, a cursory understanding of the acoustical properties of the clarinet is essential to understanding the limitations and possibilities of clarinet multiphonics.

Acoustically, the clarinet operates as a cylinder stopped at one end (mouthpiece) and open at the other end (bell).²⁰ One important factor in determining the pitch of a clarinet is its effective tube length. The effective tube length is determined largely by the location of the open tone hole closest to the mouthpiece. However, cross-fingerings can be created by closing a hole below the first open hole to allow the standing wave in the bore to travel further down the bore, effectively lengthening the tube.²¹

Another major factor that determines the pitch produced by the clarinet is the vibration mode. The harmonic series is a succession of natural overtones present in any given sound, with frequencies that are whole integer multiples of the fundamental frequency. In sounds produced by a cylindrical tube closed at one end, the even number harmonics are unsupported by the bore. Consequently, the second register, or second vibrational mode, on a clarinet is a perfect 12th higher than the first register—the second register is based on the third harmonic of the fundamental—a twelfth. In conventional clarinet playing, a register key or substitute register key is used to damp the fundamental frequency and excite the frequencies of higher harmonics. An example of a substitute register key is when the tone hole of the left-hand index finger is uncovered, or half

²⁰ Arthur H Benade, *Fundamentals of Musical Acoustics*, (New York: Dover Publications, 1990), 472-473.

²¹ *Ibid.*, 451-453.

covered, which damps the fundamental mode and allows the third mode of vibration to sound, operating on the fifth harmonic. However, using a register key is not the only method to excite the higher frequencies of higher harmonics. A player can alter the resonance characteristics of the vocal tract such that it overrides the resonance of the clarinet bore, making it possible to manipulate pitch and determine the sounding harmonic of any given fingering.²² An example of exciting a higher vibrational mode without using an additional register key or substitute register key is to play a variation of the “bugling” exercise where the bell can be either stopped or open, though the exercise is more difficult without stopping the bell. This exercise is accomplished by using a low E or low F fingering to produce higher notes in the harmonic series, where the player’s oral cavity is manipulated to excite the various overtones. The resonance of the clarinet bore is more difficult to override with longer effective tube lengths, especially in its fundamental register. The sounding note of the clarinet is determined by the reed’s oscillation frequency. The player’s vocal tract is upstream from the reed while the clarinet bore is downstream. In conventional clarinet playing, the reed’s oscillation frequency is determined by downstream resonance. However, the upstream acoustical properties can be adjusted by manipulating the tongue position to override the downstream resonance and determine the reed’s oscillation frequency.²³ To demonstrate this, the player can try to begin each clarion note without using the register key. Notes in the upper clarion register such as C and B can be easily played without the use of the

²² Jer-Ming Chen, John Smith, and Joe Wolfe, “Pitch bending and *glissandi* on the clarinet: Roles of the vocal tract and partial tone hole closer,” *Journal of the Acoustical Society of America* 126, no. 3 (September 2009): 1512.

²³ Jer-Ming Chen, John Smith, and Joe Wolfe, “How to play the first bar of *Rhapsody in Blue*,” Proceedings of ACOUSTICS 2008. Geelong, Australia, November 24-26, 2008.

register key, while notes in the middle of the register such as G and F are more difficult, and notes in the bottom of the register such as C and B are extremely difficult. Compared to the notes at the top of the clarion register, the notes at the bottom of the clarion register uses a longer effective tube length, and therefore a stronger bore resonance that is more difficult to override.²⁴

Multiphonics are largely dependant on effective tube lengths and vibration modes, emphasizing various overtones in the harmonic series by changing the internal structures of the vocal tract (henceforth referred to as *voicing*) and the use of cross fingerings. There are two main types of multiphonics: one created through only voicing changes and the other created using a combination of voicing changes and different effective tube lengths.²⁵ Multiphonics created by voicing changes alone typically use conventional fingerings, and the player manipulates their voicing so that more than one pitch in the harmonic series are excited. The other, and more common, type of multiphonic uses cross fingerings to create two different effective tube lengths in addition to proper manipulation of voicing, resulting in multiphonics with pitches that do not belong in the same harmonic series.²⁶ For these multiphonics, an open tone hole acts as a substitute register key for the longer effective tube while it simultaneously creates a bore configuration with a shorter effective tube length.²⁷ The pitch created by the short tube is affected by covered tone holes past the first open tone hole, while the pitch created by the long tube will be affected by the placement of the substitute register key, thus making it virtually

²⁴ Chen et al, "Pitch bending and *glissandi* on the clarinet," 1515.

²⁵ Watts, *Spectral Immersions*, 11, 31-98,

²⁶ Caravan, "Extensions of Technique," 95-102.

²⁷ Ibid.

impossible to accurately determine the pitches of this type of multiphonic based on fingering alone. Since manufacturers predetermine the placement of the tone holes on clarinets, not all pitch combinations can be produced, and results vary between instruments.

Various texts provide a deeper breadth of information about clarinet acoustics. For details regarding multiphonic acoustics specifically, readers can consult *Spectral Immersions: A Comprehensive Guide to the Theory and Practice of Bass Clarinet Multiphonics* by Sarah Watts. Although Watts only addresses bass clarinet multiphonics in her book, many of the acoustic principles are applicable to soprano clarinets as well, due to the two instruments sharing similar acoustical properties and designs.

CHAPTER 4

MULTIPHONIC CATALOG ORGANIZED BY PITCH

The included multiphonic catalog (Appendix A) was organized using the method used by other catalogers, in ascending order based on (1) the lower pitch and (2) the upper pitch. Only dyad multiphonics are included, but in many cases, a third pitch can be heard in the resulting multiphonic and some fingerings are capable of producing more than two pitches. The two notated pitches are the two most prominent pitches in the resulting multiphonic, determined using spectral analysis (detailed in Chapter 7 “Research Procedures”). Although producing multiphonics with more than two pitches is possible, pitch content of such multiphonics can be deduced by combining pitches of multiphonics with a shared fingering in the current catalog. Theoretically, any combination of pitches from multiphonics sharing the same fingering can be produced with the correct manipulation of the three variables in multiphonic production: voicing, embouchure, and air. Realistically, empirical evidence suggests that only triads where two of the three notes are adjacent overtones can be produced, and with great difficulty. For example, a number of possible multiphonic triads can be deduced from the following multiphonics:

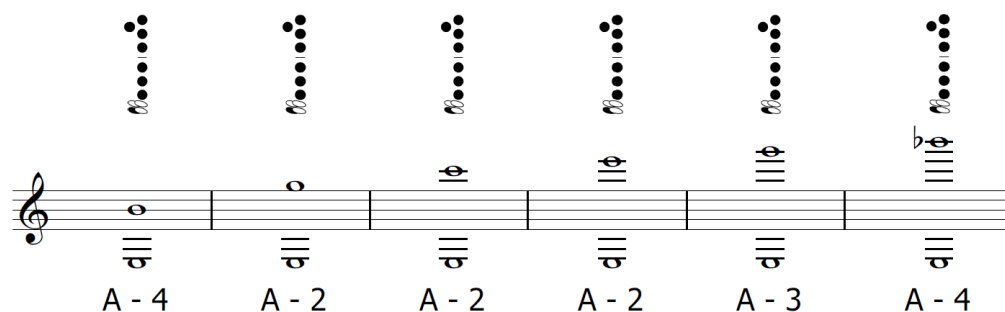


Figure 1. Multiphonics with the same fingerings.

Theoretically, a triad multiphonic containing any of the notes found in these six multiphonics is possible. However, informal experimentation suggests that a multiphonic such as E3-C6-G6 is impossible, because none of the three notes are produced on adjacent overtones. The author has been able to produce a multiphonic of E3-C6-E6 though with great difficulty. Additionally, the pitches in most multiphonics containing three or more pitches are often difficult to distinguish, with the outer pitches being dominant. Since pitch content of multiphonics with more than two pitches can be deduced from this catalog, and determining specific pitches of multiphonics with more than two pitches in performance can be difficult, only dyad multiphonics are notated in this catalog.

The notated pitches in this catalog are not exact pitches but approximations to the nearest quarter tone. As demonstrated by existing multiphonics catalogs, multiphonics produced with the same fingering on different equipment can result in different pitches. Figure 2 shows multiphonics with a shared fingering taken from two different catalogs.²⁸

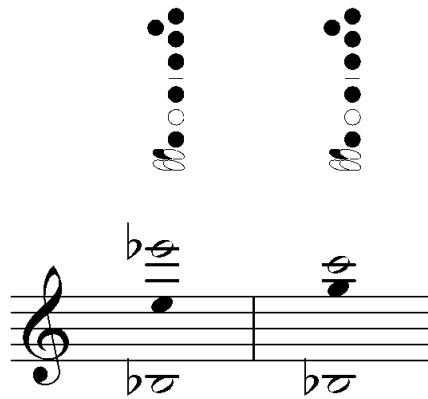


Figure 2. Multiphonics with the same fingering from Rehfeldt's and Farmer's catalogs.²⁹

²⁸ Farmer, *Multiphonics*, 42; Rehfeldt, *New Directions*, 48.

²⁹ Ibid.

The multiphonic on the left is from Rehfeldt's catalog, while the multiphonic on the right is from Farmer's catalog. As seen here, these two catalogs indicate different pitches to be produced by the same fingering. Since both Rehfeldt and Farmer determined pitches of the multiphonics based on the pitches produced by their respective instruments, and the different notated pitches do not belong to harmonics of the fundamental, it is possible that the variation between specific instruments was likely one of the causes for this discrepancy. Additionally, during the process of creating this catalog, it was discovered that pitch deviations can also occur between playing sessions for the same player using the same equipment. Due to the inaccurate nature of multiphonic tone production when performed under different physiological and mechanical conditions, pitch in the current catalog is approximated to the nearest quarter tone. Sarah Watts and Harry Sparnaay have both noticed a similar phenomenon with multiphonic pitches being susceptible to change, as previously described. These authors have also arrived at the same decision that when compiling their respective catalogs, approximate pitches are sufficient when notating multiphonics.³⁰ Multiphonics with the same notated pitches but with different fingerings should not be treated as identical. Despite having the same notated pitches, multiphonics produced with different fingerings can produce audibly different pitches when played consecutively due to pitch approximation. In cases where the multiphonics produced the same pitches using different fingerings, they can produce different timbres based on their unique bore configurations.

³⁰ Sparnaay, *The Bass Clarinet*, 134; Watts, *Spectral Immersions*, 32.

Although pitch fluctuations can occur based on a multitude of factors, such as reed, mouthpiece, instrument, and fatigue, using similar equipment can drastically lessen the deviation. As a reference, the equipment used to compile this catalog includes:

- Buffet R13 Greenline B-flat clarinet
- 66mm Taplin-Weir American style barrel
- Clark Fobes 4L mouthpiece refaced by David McClune
- Ishimori solid silver ligature
- Hand-made reeds (the same reed was used throughout the various information gathering process)

Equipment can drastically change the pitch of the multiphonics and is worth mentioning here. The most notable difference may occur from clarinets that use a different fingering system from the standard Boehm system, such as the full Boehm system and Oehler system. Special mechanisms, such as the articulated G-sharp key, automatic B-flat mechanisms, and pitch correcting mechanisms for low F may also cause pitch differences. Each brand and model of clarinet will also have a slightly different bore design and tone hole placement, which may affect pitch.

The difference between the notated and sounding pitch of different equipment setups can be more than a whole tone at times, depending on the multiphonic. As such, composers who wish to use multiphonics with exact pitches in a composition should specify that only those pitches are desired and work with a performer to ensure that these combinations are possible with their setup. Subsequent performers performing these works should also ensure that these specific combinations are possible using their equipment and be aware that they may need to alter the fingering to produce the specified pitches.

In addition to the pitch content, the catalog includes the production strategy that will be discussed in detail in Chapter 8 “Multiphonic Production Strategies,” as well as a difficulty level. It is important to note that these difficulties are assigned based on the successful production of multiphonics by attempting to produce each multiphonic while sustaining the upper note and making perceptible adjustments to only voicing. Based on empirical evidence, most multiphonics can be produced more easily when using a combination of perceptible adjustments in voicing, embouchure, and air manipulation. Additionally, readers should take into consideration that at the time difficulty levels were assigned, the author had already recently played every multiphonic at least once, since each multiphonic was played to identify its pitch content when compiling the catalog. The author is also experienced with multiphonic production and was playing multiphonics regularly at the time this study was conducted, both in repertoire as well as in various multiphonic exercises. Consequently, some multiphonics may be more difficult to produce than what the indicated difficulty level may suggest.

CHAPTER 5

MULTIPHONIC CATALOG ORGANIZED BY FINGERING

Most existing multiphonic catalogs are organized in ascending pitch order based on the lowest pitch, sometimes within several categories with predetermined sonic properties—such as is in Rehfeldt’s and Farmer’s catalogs.³¹ However, due to complications with documenting exact pitches of multiphonics described in the previous chapter, it is difficult to unify multiphonics between different catalogs and to catalog new multiphonics by pitch. As a result, composers may notate the pitch content of the same multiphonic differently based on the resources they consult. In extreme cases, a composer may notate different pitches for multiphonics with a shared fingering in the same work. From a performer’s perspective, attempting to find a multiphonic with a specific fingering in a catalog based on its notated pitch can be difficult and time consuming. To resolve this issue, the author devised a new method for organizing multiphonics (Appendix B).

The only constant notation variable for the same multiphonic in different catalogs is the fingering; therefore, a fingering-based catalog seems like a logical resource. Since few pre-existing organizational methods based on fingerings exist, the author has devised a binary style system for this purpose. Tones holes on the clarinet are covered by either fingers or pads (operated by keys)—from this point on, to avoid confusion, both tone holes covered by fingers and pads will be referred to as *keys*. Because keys on the clarinet can have two main states, depressed or undepressed, a binary system is appropriate. Although it is possible to only partially depress a key, these configurations are not used

³¹ Farmer, *Multiphonics*, 40-53; Rehfeldt, *New Directions*, 48-52.

for any of the multiphonics in this catalog and were therefore not considered. However, should the need to implement such a tone hole state arise, a simple adjustment to the fingering system can accommodate this change, such as utilizing number 2 to indicate “half-holing.” Although the system will no longer be binary if using numbers other than 0 and 1 are used, it will still function identically when used as an organizational method.

Since the standard Boehm system clarinet—the fingering system for which this catalog is intended—has 21 keys, each fingering can be indicated by using a 21-digit number of 0s and 1s—a 21-bit binary number. The alternate F/C, F-sharp/C-sharp, and E/B keys operated by the left hand are excluded when determining the number of keys on a standard Boehm system clarinet, since these keys open/close the same tone hole as the other keys producing these pitches. Each key is assigned a position within the 21 digits, and the key is indicated as undepressed or depressed by using the numbers 0 and 1, respectively. The position of the 1s within the 21-digit number indicate which keys are depressed for any given fingering. The 21-bit number is mapped in the following order:

1. Register key (R)
2. Left-hand thumb tone hole (T)
3. Throat A key (A)
4. Throat G-sharp key (G \sharp)
5. Left-hand index finger tone hole (1)
6. Left-hand middle finger tone hole (2)
7. Left-hand ring finger tone hole (3)
8. Left-hand sliver key (S)
9. C-sharp/G-sharp key (C \sharp)
10. Top trill key (B)
11. Second trill key (B \flat)
12. Third trill key (F \sharp)
13. Bottom trill key (E \flat)
14. Right-hand index finger tone hole (4)
15. Right-hand middle finger tone hole (5)
16. Right-hand ring finger tone hole (6)
17. Right-hand sliver key (S)

18. A-flat/E-flat key (Ab)
19. F/C key (F)
20. F-sharp/C-sharp key (F#)
21. E/B key (E).

Expressed in letters using the abbreviations above rather than numbers, the binary fingering would appear as:

R T A G# 1 2 3 S C# B Bb F# Eb - 4 5 6 S Ab F F# E

This system is organized based on the key's relative position on the clarinet. The numbers used in this chapter and Appendix B are grouped visually in a manner to facilitate identifying each number's corresponding key:

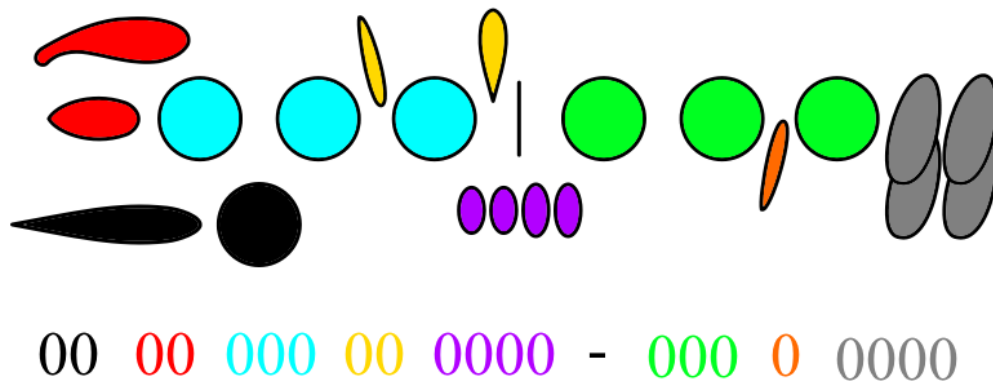


Figure 3. Color coded map of binary fingering.

When expressed in numbers, the unaltered, resting state of the clarinet, otherwise known as open G, looks like this:

00 00 000 00 0000 - 000 0 0000

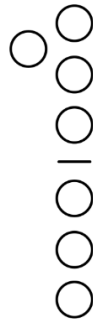


Figure 4. Fingering for open G.

Figure 5 shows the fingering for written E3, which has all finger tone holes covered and the E/B key depressed:



Figure 5. Fingering for E3.

Expressed in numbers:

01 00 111 00 0000 - 111 0 0001

Figure 6 demonstrates a more complicated fingering using a cross-fingering configuration: altissimo E-flat6. One common fingering for this note includes:

- register key depressed
- left hand thumb
- middle finger
- ring finger tone hole covered
- right hand index finger tone hole covered

-

Expressed in numbers:

11 00 011 00 0000 - 100 1 1000

It is important to note that when depressing the A key, the G-sharp key is also depressed. However, in the binary fingering system, the corresponding digit for the G-sharp key will be indicated as undepressed by a 0 since it is not physically being depressed by the player. Likewise, when the digit corresponding to the F-sharp/C-sharp key or E/B key is depressed, the digit corresponding to the F/C key will be indicated as undepressed by a 0 even though depressing the E/B and F-sharp/C-sharps keys will also depress the F/C key.

Initially, this fingering system may seem overwhelming or confusing to the user, especially when side keys and trill keys are involved. Consequently, some fingerings do

not appear where one may expect them to be within the catalog. To become familiar with the system, it is recommended that the user first express the fingering in question as a 21-bit binary number as per examples above, by identifying which keys are depressed. The following table will facilitate expressing fingerings as binary numbers. First identify the depressed keys of the fingering in question, then fill the corresponding box in the table with the number 1 and the remaining boxes with 0 to generate the binary fingering.

[illegible]

Harry Sparnaay also organized his bass clarinet multiphonic catalog by fingering, based on the conventional fingering the multiphonic fingering most closely represented.³² This method of organization would seem more intuitive at first, and was considered for the current catalog. However, when dealing with a large number of cross fingerings—a fingering where tone holes are covered past the first open tone hole—as is the case in the current catalog, it is difficult to determine which conventional fingering some multiphonic fingerings most closely resemble, if any. Additionally, if the reader wanted

to find a specific multiphonic by its fingering but did not agree with the author on which conventional fingering it most closely resembles, it would be nearly impossible to find the multiphonic in question, short of looking at every multiphonic in the catalog.

CHAPTER 6

ULTRASOUND IMAGING

Ultrasound has been used to examine tongue surface contours during speech and other vocal activities since 1980.³³ The procedure is non-invasive and allows real time data collection, making it ideal for this type of study. A basic understanding of ultrasound imaging is beneficial to understanding the nature of this study as well as its limitations.

Ultrasound uses the principles of echolocation to visualize internal structures. High frequency sound waves generated by a transducer propagate from the transducer through various media until it meets an acoustical impedance mismatch, such as the tissue/air interface at the surface of the tongue, where the sound waves are reflected back to the transducer. A greater difference in acoustical impedance will reflect more acoustical energy. The ultrasound machine uses the transit time of the sound waves to generate a precise distance for the reflective interface, while the amount of energy reflected is used to define contrast. Many samples collected across an array of pulse transmissions allow the machine to create a two-dimensional image. Sound waves reflected at normal incidence (90-degrees) between the direction of propagation and the reflective interface reflect the most energy, thus providing an optimal image. Generally, as sound waves reflect further from the optimal 90-degree angle, image clarity deteriorates, or in extreme cases, results in no image of the interface.³⁴

In this study, the transducer was placed submentally—under the chin—to produce an image of the tongue's midsagittal plane. The midsagittal plane divides the

³³ Melissa A. Epstein and Maureen Stone, "The Tongue Stops Here: Ultrasound Imaging of the Palate," *Journal of the Acoustical Society of America* 118, no. 4 (2005): 2128.

³⁴ Wayne R. Hedrick, David L. Hykes, and Dale E. Starchman. *Ultrasound Physics and Instrumentation*, (New York: Churchill Livingstone, 1985), 9-15, 43, 50.

human body into left and right halves and is where the most tongue motion can be observed while performing multiphonics. In the resulting image, several important structures within the oral cavity are visible: the tongue, the jaw bone shadow, and the hyoid bone shadow. The acoustic impedance mismatch between the tissue/bone interface and tissue/air interface reflects the sound waves back to the transducer, creating an image of the tongue surface and casting acoustic shadows of the hyoid and jaw bones (figure 7). Additionally, the outline of the palate can be traced by pressing the tongue against the palatal bone, such as when swallowing. By eliminating the air between the tongue and the palate, the ultrasound beam reflects off the palate, producing an image of the palate contour. The acoustic shadows of the jaw and hyoid bones are used as reference points to determine the relative position of the tongue in this study.

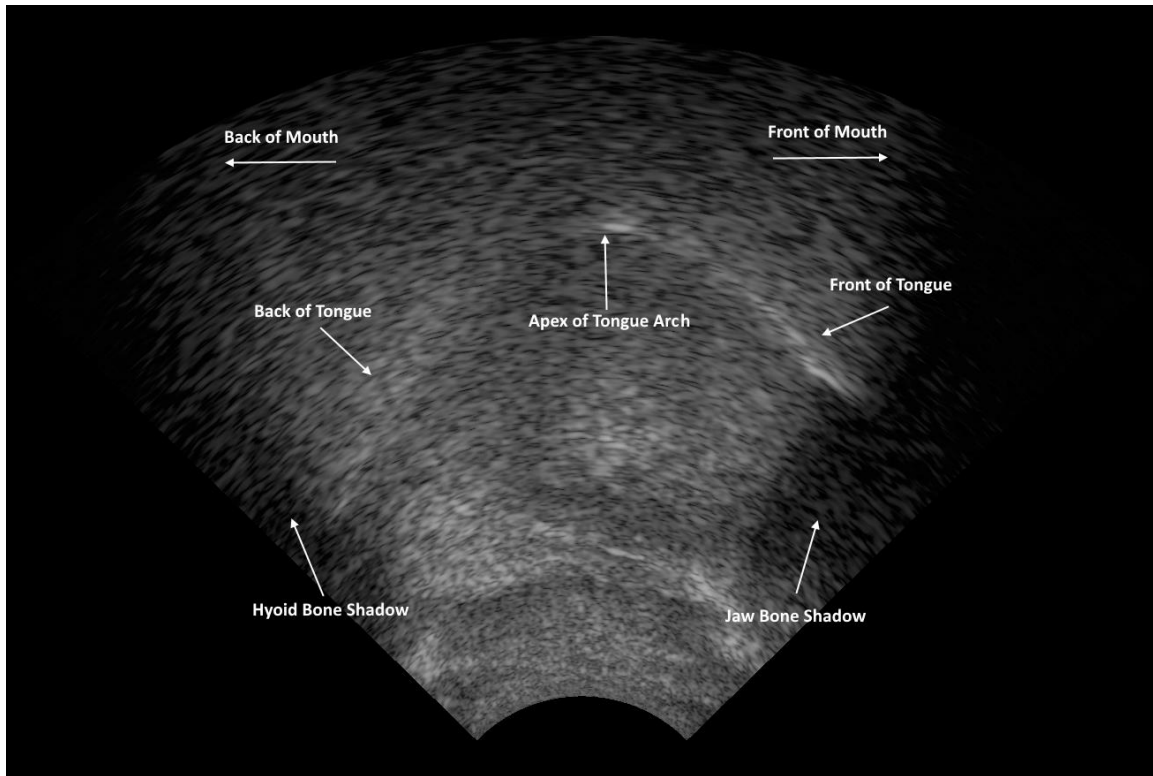


Figure 7. Ultrasound image of the tongue at rest labeled with areas of interest.

Ultrasound imaging has several limitations, including the acoustic shadows cast by the hyoid and jaw bones. Although these shadows are important to interpreting the image, they obstruct potentially important segments of the tongue. In this study, the hyoid bone obstructs the tongue root, which is active when producing multiphonics, as discussed later in Chapter 8 “Multiphonic Production Strategies.” The jaw bone can obstruct the tip of the tongue in the ultrasound image depending on the position of the tongue. Although this obstruction does not have a great effect on the results of this study, it is important to note for future studies. Another limitation is the clarity of the image. Ultrasound image clarity can vary greatly between subjects compared to images produced by some other imaging methods, such as x-ray, magnetic resonance imaging, and fiber optic imaging. Some individuals produce a very clear image while others may produce an unclear image, since various physical attributes of the individual can affect image clarity.³⁵ The results can be difficult to interpret in cases where a clear image cannot be produced. Ultrasound is also suboptimal for imaging steep tongue contours. The further an interface departs from an angle of normal incidence, less energy is reflected back to the transducer. Steep tongue contours, such as when saying the vowel /i/, as in “steep,” can result in no tongue surface image! In extreme cases encountered in this study, steep tongue contours resulted in a discontinuity in the tongue contour. Finally, ultrasound only creates a two-dimensional image within a given plane. Ideally, a three-dimensional model would be created to accurately depict the entire tongue. Although it is possible to create a three-dimensional model from two-dimensional ultrasound images or from volumetric ultrasound machines, only two-dimensional images were examined in this study.

³⁵ Maureen Stone, “A Guide to analysing tongue motion from ultrasound images,” *Clinical Linguistics & Phonetics* 19, no. 6-7 (2005): 462-463.

For additional information on ultrasound imaging, readers can refer to *Ultrasound Physics and Instrumentation* by Hedrick, Hykes, and Starchman,³⁶ the main text from which this section is derived.

³⁶ Hedrick, et al., *Ultrasound Physics and Instrumentation*.

CHAPTER 7

RESEARCH PROCEDURE

The goals of the study include creating a catalog of dyad multiphonics that performers may encounter in repertoire and identify tongue-related production strategies that facilitate these multiphonics through empirical observation. The catalog is compiled from existing catalogs and multiphonics found in repertoire in attempt to unify, update, and consolidate these resources. However, due to already having found ten notable existing catalogs and potentially uncatalogued multiphonics, only a portion can be reasonably catalogued at this time. Notable catalogs published include ones by William O. Smith, Phillip Rehfeldt, Gerard Farmer, and Bruno Bartolozzi, to name a few.³⁷ Noteworthy online catalogs are provided by Gregory Oakes, Nicolas del Grazia, Heather Roche, and Timothy Reichard.³⁸ Catalogs can also be found in dissertations such as those by Ronald Caravan and Holly Haddad.³⁹

The current catalog is compiled from existing catalogs by William O. Smith, Phillip Rehfeldt, and Gerald Farmer, as well as from every composition by Eric Mandat published before 2017. Catalogs by Smith, Rehfeldt, and Farmer were selected because these are the three printed catalogs that are most widely consulted, each containing

³⁷ Bartolozzi, *New Sounds*, 37-49; Farmer, *Multiphonics*, 40-54; Rehfeldt, *New Directions*, 48-51.

³⁸ Nicolas del Grazia, "Clarinet Multiphonics," <http://www.clarinet-multiphonics.org/clarinet-multiphonics.html>.0020 (accessed March 20, 2017; Gregory Oakes, "Clarinet Extended Techniques," <http://www.gregoryoakes.com/multiphonics/index.php> (accessed March 20, 2017; Timothy Reichard, "The Woodwind Fingering Guide," http://wfg.woodwind.org/clarinet/cl_mult_1.html (accessed March 18, 2017; Heather Roche, "... On Closed Dyad Multiphonics for Bb Clarinet," *Heather Roche*, July 2, 2014, <https://heatherroche.net/2014/07/02/on-close-dyad-multiphonics-for-bb-clarinet> (accessed March 30, 2017); Heather Roche, "Spectral Multiphonics (Bb and Bass)," *Heather Roche*, September 26, 2016, <https://heatherroche.net/2016/09/26/spectral-multiphonics-bb-and-bass> (accessed March 29, 2017).

³⁹ Caravan, "Extensions of Technique," 69-73; Holly Ann Haddad, "The History and Comparison of Three Diverse Systems of Producing Multiphonics of the B-flat Boehm System Clarinet." (DMA diss., University of Arizona, 2006), 114-134.

approximately 150 multiphonics. Another printed resource worth mentioning is by Bruno Bartolozzi. However, since his catalog only contains a very small number of multiphonics, and the notation for fingerings is unconventional and without explanation, it was not included. Online catalogs are also not included at this time, due to the frequent updates and revisions made to online information and the large number of multiphonics already in the current catalog. Eric Mandat has composed a large number of works for clarinet, most of which include multiphonics. These multiphonics are not catalogued but recur frequently throughout his works. Considering the popularity of Mandat's work in the clarinet community, it is beneficial and practical to include these multiphonics in the current catalog.

Mandat's multiphonic pitches and fingerings were catalogued and cross-referenced with other catalogs. The following works were consulted, listed alphabetically, along with their year of publication:

- 2 teeZ (2013)
- 3 for 2 (2002)
- Black Swirls (2004)
- Bipolarang (2008)
- Chiral Symmetries (2013)
- Coconut Candy (2000)
- Double Life (2007)
- Etude for Barney (1990)
- Folk Songs (1986)
- The Jungle (1989)
- Lines, Spaces, Planes (2010)
- The Moon in My Window (2007, revised 2010)
- Music for Clarinets (1994)
- One Liners (2000)
- Peg and Hole Collide (2006)
- Ritual, Version B (2000)
- Rrowzer! (2005)
- Shadows from Flames (2011)

- Sub(t)rainS O' Strata'sfearS (1996)
- Tricolor Capers (1980)
- What Elsa's New (1997)

Each multiphonic was played to determine its pitch, and any duplicate multiphonics were eliminated. A duplicate multiphonic is one that has the same fingering as another multiphonic, but the different notated pitches belong in the same partial. For example, several different multiphonics can be produced using an E3 fingering. With the lower note of E3, multiphonics with the upper note B4, G5, C6, E6, and more are all possible. These multiphonics are considered different because the upper notes are different overtones of the fundamental. However, the same fingering can produce a multiphonic of E3 and B5 by bending the pitch of the upper note down from C6. This is not considered a different multiphonic because the upper note is achieved through pitch bending and is not a different overtone of the fingering. Multiphonics with more than two notated pitches are classified as separate dyads. Spectral analysis was used to determine the two most dominant frequencies in each multiphonic. Figures 8, 9, and 10 are frequency spectrum graphs generated by the Android application "TonalEnergy Tuner",⁴⁰ displaying the most dominant frequencies in the sound. Figure 8 shows the graph when playing the multiphonic of G4 and C6 produced using the conventional fingering for C6 (register key and thumb tone hole), the two most dominant frequencies are the two highest peaks in the graphs. Principal frequencies in figure 8 are the same frequencies as the two most dominant pitches in figures 9 and 10, which are the upper and lower note of the multiphonic produced using the multiphonic fingering, respectively.

⁴⁰ Philip Geiger, "TonalEnergy Tuner," version 1.5.4, Sonosaurus LLC, <https://play.google.com/store/apps/details?id=com.sonosaurus.tonalenergytuner&hl=en> (accessed March 19, 2018).

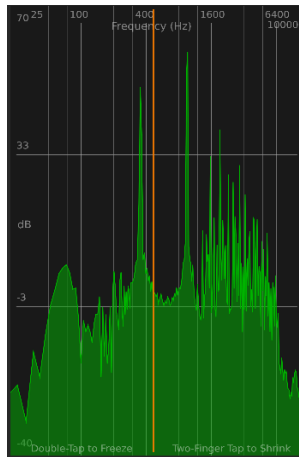


Figure 8. Frequency spectrum graph when playing multiphonic G4 and C6.

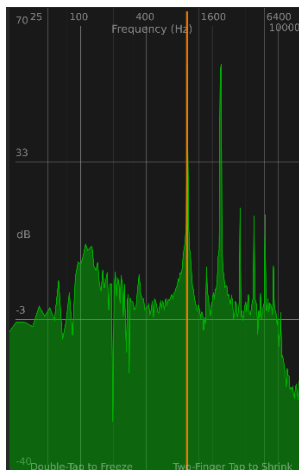


Figure 9. Frequency spectrum graph when playing the upper note of the multiphonic G4 and C6.

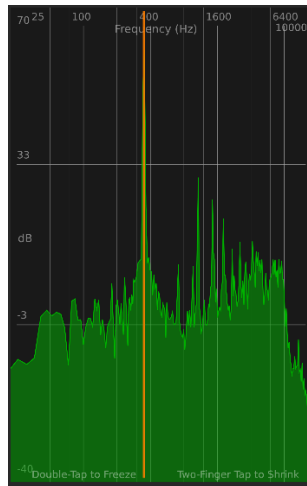


Figure 10. Frequency spectrum graph when playing the lower note of the multiphonic G4 and C6.

In cases where different two-pitch combinations can be emphasized as the two most dominant frequencies, each combination is classified as a different dyad multiphonic possibility. The catalog was reorganized by fingering and notated using Sibelius 7, and fingering diagrams were generated from Fingering Diagram Builder, an online resource created by Bret Pimentel for creating fingering diagrams for wind instruments.⁴¹

The catalog created from Mandat's works was cross-referenced by fingering against William O. Smith's catalog, and any multiphonics with a different fingering or pitch were documented. Each new multiphonic in Smith's catalog was played to determine its pitches using spectral analysis and added to the current catalog. This process was repeated for catalogs by Phillip Rehfeldt and Gerald Farmer. The resulting catalog contains 604 dyad multiphonics produced using 358 unique fingering combinations.

⁴¹ Bret Pimentel, "Fingering Diagram Builder", <http://fingering.bretpimentel.com> (accessed May 19, 2017 through June 05, 2017).

Once the process of compiling the new catalog was complete, each multiphonic was played to investigate a possible production strategy and to assign a difficulty rating from 1 to 5, with 1 being the easiest to produce and 5 being the hardest to produce. The production strategy was determined by a mixture of subjective perception and observation using ultrasound imaging. Initially, the author attempted to play every multiphonic 10 times, noting the perceived *voicing* adjustments necessary to produce them. A difficulty rating was also assigned to each multiphonic based on the number of times the multiphonic was successfully produced out of the 10 attempts. The fingerings that produced multiphonics more easily than the individual pitches were assigned a difficulty level of 1. Multiphonics that could be produced consistently (9 to 10 times out of 10) were assigned a difficulty level of 2. Multiphonics that were relatively easy to produce (6 to 8 times out of 10) were assigned a difficulty level of 3. Multiphonics that were difficult to produce consistently (3 to 5 times out of 10) were assigned a difficulty level of 4. Multiphonics that were very difficult to produce (1-2 out of 10 or requiring more than 10 attempts to successfully produce once) were given a difficulty level of 5. An attempt was considered successful when both pitches were audible for a duration of at least 2 seconds. The difficulties of sustaining both pitches beyond 2 seconds and of producing either of the individual notes using the multiphonic fingering was not considered when determining the difficulty for each multiphonic.

The multiphonic production strategy investigation was repeated another four times, however, with each multiphonic played enough times to determine the strategy of production rather than 10 attempts, noting any discrepancies in perceived voicing changes. During repetitions of this process, the order in which the multiphonics were

played was changed to avoid perception being consistently influenced by that of another multiphonic. Using Google Sheets, the measure number of the multiphonic as it appears in both catalogs by pitch and fingering were recorded along with production strategy and difficulty. Multiphonics were played once in the following orders: (1) the catalog organized by pitch, (2) fingering, (3) production strategy, (4) level of difficulty, and (5) completely randomized using the “randomize range” function in Google Sheets. After five repetitions and taking note of the production strategy, specific multiphonics were selected to be played while using ultrasound to observe the movement of the tongue to provide visual feedback and ensure accuracy of perception. The multiphonics selected for observation were not perceived as having the same voicing adjustments in at least four out of the five repetitions. If the voicing adjustments were perceived as the same in four out of the five repetitions, the one repetition with different perceived voicing was attributed to human error, whether in perception, documentation, production using adjustments other than voicing, or other unknown factors. Additionally, from each group of multiphonics with similar production strategies, four multiphonics of varying intervals were selected for observation. Multiphonic production strategies were defined and grouped based on the direction of tongue motion in making the necessary adjustments. Initially, the multiphonics were selected from seven groups of different production strategies. After the first ultrasound exam, it was noted that three of the production strategies that were perceived as different were in fact the same as one of the other production strategies and were subsequently combined, resulting in the final group of four strategies. Multiphonics selected for observation in subsequent ultrasound exams were from these four groups of production strategies. Of the multiphonics selected from

each production strategy group, depending on availability, one was of an interval less than an octave, one between one and two octaves, one between two and three octaves, and one more than three octaves.

The ultrasound exams were performed at the Performance Physiology Research Laboratory at Arizona State University using a Terason T3000 Ultrasound System.

During the ultrasound investigation, the transducer was hand held submentally to examine midsagittal tongue motion at a scan depth of 9 centimeters. The investigative nature of the initial inquiry did not require transducer stabilization. Additionally, when hand held, the transducer angle can be easily adjusted to examine different parts of the tongue. Since ultrasound imaging was used only to confirm or correct subjective perception during this stage of the study, only qualitative data were observed and recorded. During the ultrasound investigation process, the tongue motion while playing the multiphonics was compared to the previously perceived motion. In cases of discrepancies, the motion seen using ultrasound was documented as the correct perception.

The process of playing through the multiphonic catalog five times and selecting a representative sample for ultrasound imaging was repeated four times. No multiphonics were selected more than once for ultrasound imaging. By the end of this process, the multiphonic catalog was played in its entirety 20 times and ultrasound imaging was used four times to reinforce perception. After the third repetition, no discrepancies were noted between multiphonics on different repetitions and no misperceptions were noted during the ultrasound imaging process. Each multiphonic was grouped into one of four strategies

of production detailed in Chapter 8 “Multiphonic Production Strategies” after the third ultrasound investigation.

Tongue contour images were captured during the fourth ultrasound investigation. An Articulate Instruments Probe Stabilization Headset was fitted to the author. The headset secures the ultrasound transducer submentally through contact points on the top, side, and back of the head, cheekbones, and a ratchet strap mechanism (figure).The fixed position of the transducer, relative to the skull, allows for quantifiable data analysis, and the still images are easier to compare between tasks.

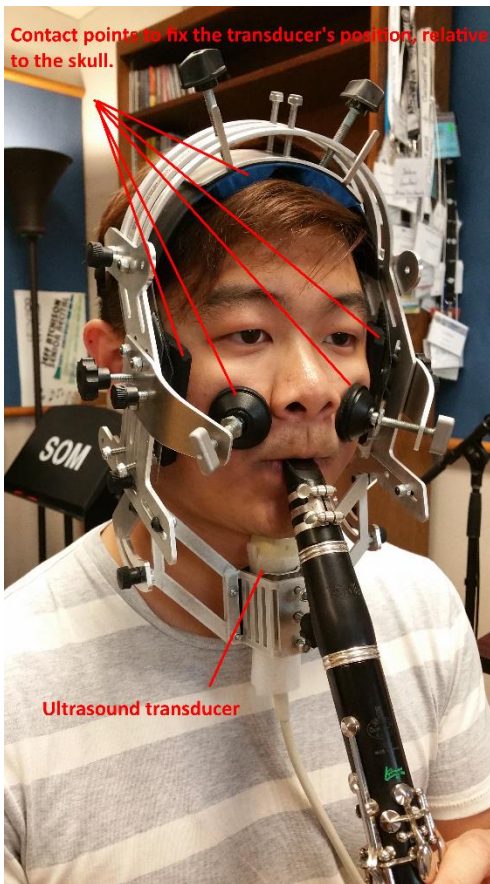


Figure 11. Image of the Articulate Instruments Probe Stabilization Headset fitted to the author.

During the investigation, the resting position of the author's tongue was first captured. The author then played eight multiphonics, with two multiphonics from each strategy of production. Images were captured of the tongue position when performing the upper note, lower note, and the multiphonic all while using the multiphonic fingering. The multiphonics selected were easy to produce consistently and required a significant perceived change in tongue position, so that when comparing images with the naked eye, the change in tongue position could be identified easily. Two multiphonics from each production strategy were selected in anticipation that one of the two may utilize a tongue shape that does not produce a clear image. Since production strategy is defined by the direction of motion rather than the shape of the tongue, multiphonics in the same production strategy category can have distinctly different tongue shapes, some of which may not produce a clear image. The clearer image of the two multiphonics from each production strategy is used in Chapter 8 of this document. Images were captured in tagged image file format (commonly abbreviated as TIFF or TIF) for the best image quality.

To minimize error, the author played every multiphonic multiple times and carefully documented his perception. Ultrasound investigations were also conducted after every five repetitions of playing every multiphonic to provide visual feedback and ensure perception accuracy.

To evaluate the effectiveness of this study's results as a resource for performers, eight test subjects were selected to learn 10 multiphonics. The test subjects included four graduate students and four undergraduate students from the clarinet studio at Arizona State University. These subjects have all encountered multiphonics previously in

repertoire, although some students had significantly more experience than others. The test subjects were given a questionnaire to gather information about their equipment and gauge their experience with multiphonics, an excerpt from Chapter 8 “Multiphonic Production Strategies” containing the four strategies of producing multiphonics, and 10 multiphonics. The same 10 multiphonics selected were used for every test subject and included at least two multiphonics from each production strategy. Subjects were given five days to learn how to perform these multiphonics using only the provided written material and previous experience; seeking help from outside sources was prohibited. On the sixth day, ultrasound imaging was used to observe each subject’s tongue motion while they performed the multiphonics. The probe headset was fitted to each subject with them seated facing away from the ultrasound monitor. Still images of tongue shape were captured when playing the upper note, lower note, and multiphonic using the appropriate fingering for each multiphonic. The goal of this test was to identify whether the subjects were able to follow the instructions provided without visual feedback from the ultrasound machine, whether the information provided was helpful in the process of learning how to produce multiphonics, and whether the motion each subject used to produce each multiphonic was consistent with the findings detailed in Chapter 8.

CHAPTER 8

MULTIPHONIC PRODUCTION STRATEGIES

During the investigative process, the author observed that voicing plays a critical role in successful multiphonic production on the clarinet. Pedagogical resources define voicing in numerous ways; in the context of this study, it is defined as the tongue position inside the oral and pharyngeal cavity during clarinet performance. Changing tongue position to achieve desired tonal qualities on the clarinet is common practice among many clarinetists. Although making changes to embouchure or parts of the vocal tract other than the tongue to achieve a desired sound is certainly possible, the tongue is the more mobile structure in the vocal tract anatomy, making it the most logical structure for affecting changes to sound. Students are usually taught to maintain a high tongue position while playing the clarinet, which has become the default way of describing voicing for many clarinetists. Since a common problem when teaching voicing is that people are generally unaware of what their tongues are doing,⁴² pedagogues have developed various methods to manipulate the tongue into the desired position. A few methods the author has encountered throughout his studies include vocalizing syllables, partial and register control, and pitch manipulation. Since the desired high tongue position used for playing the clarinet is not the resting position of the tongue, as seen with all subjects in this study, we can assume that clarinetists were trained to manipulate their tongue into this desired position, regardless of whether it is done consciously or subconsciously. Maintaining a high tongue position is one of many ways voicing can be manipulated since the tongue is

⁴² Matthew Patnode, "A Fiber-optic Study Comparing Perceived and Actual Tongue Positions of Saxophonists Successfully Producing Tones in the Altissimo Register," (DMA diss., Arizona State University, 1999), 143.

capable of forming many shapes. Changing tongue shapes to produce different vowels in speech is an example of tongue manipulation we encounter in daily life. Similarly, in clarinet performance, we can manipulate our voicing in various ways to achieve different effects, such as altering timbral qualities and pitch. With very specific manipulations, one of the effects that can be achieved is multiphonic production.

When discussing voicing manipulation relative to multiphonic production in the current study, certain assumptions were made about the readers' ability to consciously manipulate their voicing based on the expected proficiency of the intended audience for this study. To effectively utilize and follow the instructions for multiphonic production strategies in this chapter, readers should first be able to perform the following voicing exercises with relative ease:

1. Using the conventional fingering for C6, play a C6 and bend the pitch down at least a major third to an A-flat5 without changing fingering or altering embouchure.
2. Using the conventional fingering for C6, play a C6 and then play a G4 (subtone) without perceptible change in embouchure force.
3. Using the conventional fingering for E3, play the notes G5, C6, E6, and G6 without changing the fingering or using the register key.

Performing these voicing exercises helps develop the performer's ability to consciously control and manipulate their voicing, which is essential to being able to produce most multiphonics.

The correct voicing for producing any multiphonic can be described as an intermediate of the voicings for producing the individual notes of the multiphonic. The use of an intermediate voicing is most evident when looking at the ultrasound images captured for multiphonics produced using **Strategy C** in the later portion of this chapter.

The first step in learning to produce any multiphonic is to play the individual notes of the multiphonic using the given multiphonic fingering. Using similar voicing manipulations required to perform the voicing exercises listed above, the performer should be able to play most of the individual pitches of multiphonics in the catalog using its multiphonic fingering. If the performer is unable to play the individual notes of a given multiphonic using the multiphonic fingering, there is a chance that the performer will be unable to perform the multiphonic. Similarly, the performer is unlikely to be able to produce multiphonics with an upper note beyond the performer's comfortable playing range.

The performer should attempt to produce the multiphonic after successfully producing the individual pitches of the multiphonic. As previously mentioned, producing multiphonics requires a very specific voicing with a small margin for error. For example, the voicing adjustment for multiphonic produced using **Strategy B** is very minute—the shape difference observed in captured ultrasound images for the upper note and multiphonic is difficult to identify with the naked eye. Accurately perceiving, describing, and mimicking voicing are extremely difficult tasks even for professional musicians,⁴³ resulting in different and conflicting descriptions, ideas, and approaches to teaching multiphonic production. The student is often left to discover the production strategies of multiphonics on their own through a trial and error process, which may or may not be successful. Through investigations using technology and informed perception over numerous trials, as described in Chapter 5 “Research Procedure,” it was found that every multiphonic can be facilitated using one of four production strategies (A, B, C, and D) as indicated for each entry in the catalogs found in the appendices of this document.

⁴³ Ibid.

While only four production strategies are included in this study, these four strategies are merely suggestions for learning how to produce multiphonics and are not the only possible strategies. Each of the four production strategies requires the performer to play the upper note of the multiphonic, and while sustaining it, manipulate the voicing in a certain way to allow the lower note to sound. In practice, some multiphonics may be easier to produce when approached from the lower note, or even using a completely different production strategy. However, there are several reasons and benefits to approaching multiphonics from the upper note. As discussed in Chapter 3 “Acoustics of Multiphonics,” a slight deviation from the ideal voicing will influence the tonal qualities of higher notes more than lower notes, due to the weaker bore resonance of higher notes. Therefore, higher notes require more precise voicing than lower notes to achieve desired tonal qualities. The influence of voicing over sound production is a characteristic that multiphonic production shares, and since the voicing to produce the upper note is more precise and often closer to the desired voicing to produce the multiphonic than the voicing of the lower note, smaller alterations are necessary to produce multiphonics when starting from the upper note. The upper note is often, though not always, the more difficult of the two notes to produce using a given fingering. Consequently, attempting to produce the lower note while sustaining the upper note is easier than vice versa.

The instructions to produce every multiphonic with the same production strategy is the same, yet the voicing required to produce each of these multiphonic is different. The only difference between the instructions for multiphonics with the same production strategy is the voicing to which the alterations are applied. Especially for multiphonics that share a fingering and lower note, the instructions for producing these multiphonics

would be identical if they asked the performer to start from the lower note. For example, the following multiphonics share the same lower note and are produced using the same fingering, and both can be produced using production **Strategy A**:

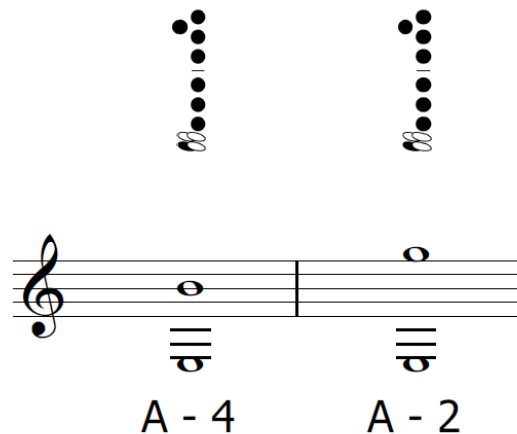


Figure 12. Example of two multiphonics sharing the same lower note, fingering, and production strategy.

The only difference between the production strategies for the two multiphonics in figure 11 is the tongue position to which alterations are applied—the voicing to produce B4 and G5 using the given multiphonic fingering. If the instructions required the performer to start on E3, the instructions to produce these multiphonics would be identical, both applying the same alteration to the tongue position for playing E3, which would be quite difficult for this particular example.

Before providing detailed descriptions of each multiphonic production strategy, basic descriptions of the four production strategies are listed here for reference:

- A. Lowering the back of the tongue while sustaining the upper note
- B. Raising the back of the tongue while sustaining the upper note
- C. Changing the tongue position to that of the lower note while sustaining the upper note

- D. Raising the root of the tongue (a sensation similar to constricting the throat) while sustaining the upper note

Multiphonics produced using **Strategy A** mostly utilize a fingering that results in a bore configuration likely to produce a pitch in the chalumeau register (e.g., any multiphonic using a conventional fingering for a note in the chalumeau register). To produce these multiphonics, first play the upper note. While sustaining, slowly lower and retract the back part of the tongue while maintaining the tongue position in the middle portion of the tongue until the lower note can be heard in addition to the upper note. The performer can think of relaxing the tongue while sustaining the upper note can facilitate performing the described motion to produce these multiphonics. Multiphonics with larger intervals require smaller but more precise adjustments. This is likely due to voicing having more influence over pitch in higher tessitura, and having less influence over pitch in lower tessitura. As such, the multiphonic voicing is very similar to that of the upper note to facilitate production of the higher pitch, while having minimal effect on the lower note. For some multiphonics with an interval less than a perfect fifth, there is almost no perceptible change in voicing. During the current study, every multiphonic was produced with only perceptible adjustments to voicing. In practice, a slight decrease in embouchure force and air can help the production of multiphonics produced with this strategy.

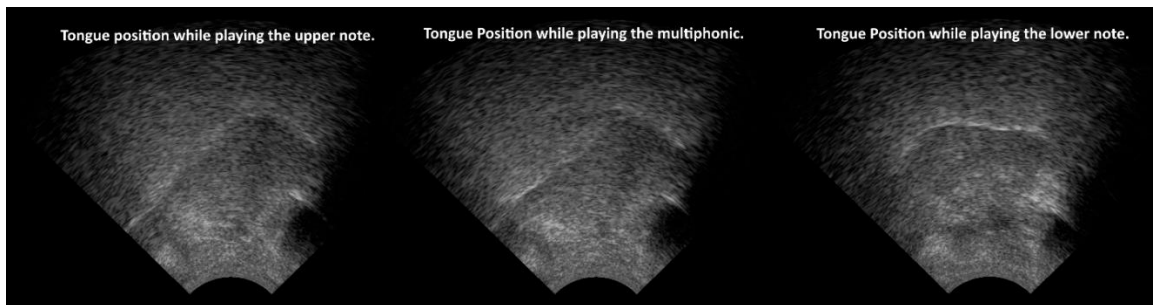


Figure 13. Ultrasound images of the tongue while playing a multiphonic produced using Strategy A (E3 and C6). The back of the tongue is lowered while the apex of the tongue arc remains relatively unchanged. Note how the tongue contour for the

multiphonic is more similar to the upper note tongue shape than the lower note tongue shape.

Multiphonics produced using **Strategy B** are generally ones that use a fingering involving the register key or an alternate register key while simultaneously producing the fundamental pitch. Some examples of multiphonics in this category include those using a conventional fingering for a note in the clarion register while producing the clarion note as well as a lower note. To produce these multiphonics, first play the upper note. While sustaining, raise the back of the tongue until both pitches are audible. The performer can think about trying to touch the ridge dividing the hard and soft palate with the back of the tongue, but moving very slightly, to facilitate performing the action described for this production strategy. Similar to multiphonics produced using **Strategy A**, multiphonics with larger intervals between the notes require smaller but more precise adjustment. Multiphonics produced using **Strategy B** that use bore configurations with longer effective tube lengths are more difficult to produce (especially if the upper note is in the clarion register) than ones that use a shorter effective bore length. For example, the following multiphonics are both produced using **Strategy B**.

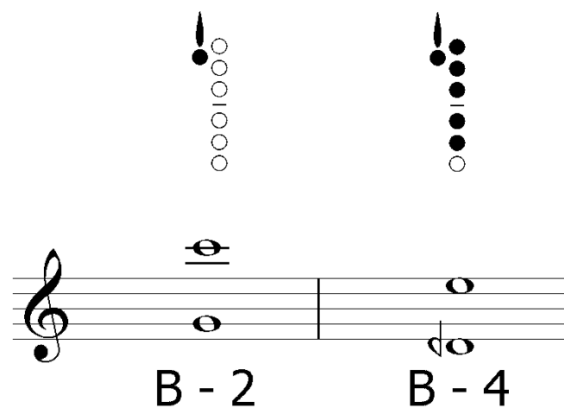


Figure 14. Example of two multiphonics produced with Strategy B using different effective tube lengths.

However, the first multiphonic has a difficulty level of 2 while the second multiphonic as a difficulty level of 4. One of the reasons the second multiphonic is more difficult to produce is due to the longer effective tube length of the bore configuration, since the lower note is much more difficult to produce using the given multiphonic fingering in the second multiphonic. In general, most of the multiphonics produced using this strategy can be achieved with only voicing adjustments, helped by a slight decrease in air pressure. Although embouchure force was not measured in the current study, the author noticed that a perceptible adjustment in embouchure force is often unnecessary for producing these multiphonics; in fact, the upper pitch intonation of some multiphonics can be improved by slightly *increasing* embouchure force. Since the adjustments made for multiphonics produced using **Strategy B** is very minute, ultrasound images were analyzed using ImageJ⁴⁴ to help identify tongue motion. ImageJ is an image processing program used to analyze, edit, and process images. For this study, it was used to measure

⁴⁴ Wayne Rasband, "ImageJ: Image Processing and Analysis in Java," version 1.8.0_112 for Microsoft Windows, <https://imagej.nih.gov/ij/download.html> (accessed March 19, 2018).

the distance between the edge of the image sector and the tongue surface. The distance between P (2.52, 3.95), defined by the posterior edge of the imaging sector, and the coordinate where the tongue contour intersects the $x=2.52$ axis is measured (as seen in figure 14) on ultrasound images of the tongue while producing the upper note and multiphonic. The coordinate where the tongue contour intersects the $x=2.52$ axis is 1.80mm higher in the image captured while playing the multiphonic. The scan depth was used to convert pixel measurements to millimeters.

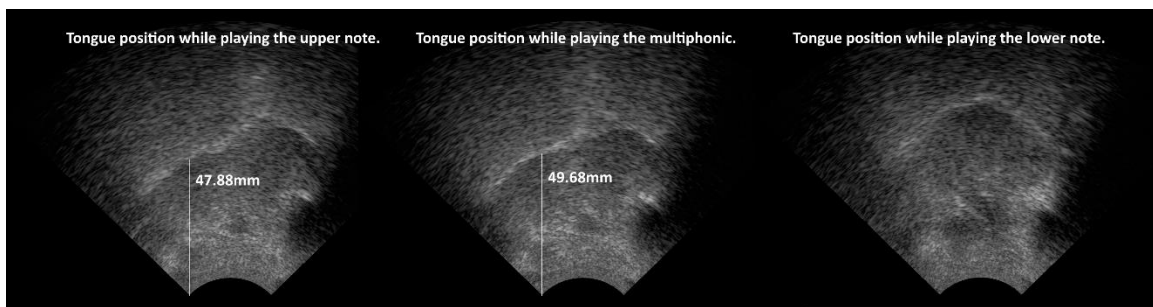


Figure 15. Ultrasound images of the tongue while playing a multiphonic produced using Strategy B (E4 and G5). The back of the tongue is slightly raised, and the tongue contour is more rounded.

Multiphonics produced using **Strategy C** avoid notes from the chalumeau register. These include multiphonics that use a conventional clarion register fingering to produce the clarion note and a higher note. No consistent trends were noticed between different multiphonics produced using this strategy. The multiphonic tongue position appears to be an intermediate position—usually more similar to the voicing of the upper note—of the voicings to produce each pitch individually. To produce these multiphonics, start by playing both notes individually and take note of the voicing for both notes. Then, starting on the upper note, slowly alter the voicing to that of the lower note until both pitches speak. The author noticed during the investigative process that that multiphonics

produced using this strategy are more challenging to master, though the difficulty is in the ability to sustain and not over-adjust rather than in finding the correct voicing. In the initial attempts, the performer will likely be able to produce the multiphonic, though only for a few milliseconds, before the upper note disappears. The performer should continue to experiment with the amount of adjustment and slight variations in the alterations until the multiphonic can be sustained. Since no consistent trends were noticed in the voicing manipulation of multiphonics produced using this strategy, it is difficult to offer generalized suggestions on how to adjust embouchure or air to produce these multiphonics. Fortunately, very few multiphonics are produced this way, and they can all be produced solely with perceptible changes in voicing.

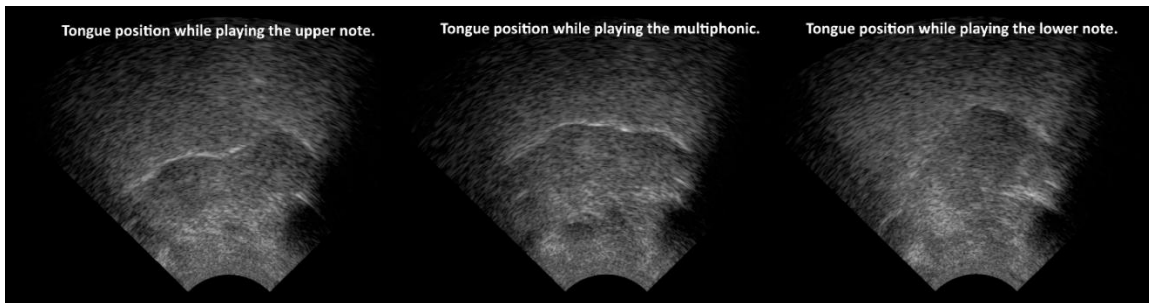


Figure 16. Ultrasound images of the tongue while playing a multiphonic produced using Strategy C (F-sharp5 and E-flat6). The back of the tongue moves up and forward, forming a shape that has characteristics of the voicing for the lower note, where there is only one apex and the tongue position is higher and more rounded.

Multiphonics produced with **Strategy D** include an upper note between E-flat6 and G6 and a lower note between G4 and B-flat4. These multiphonics require a manipulation similar to those produced using **Strategy B**. Start by playing the upper note of the multiphonic, but instead of raising the back portion of the tongue, the tongue root—which is obscured by the hyoid bone—is raised, while no motion can be observed in the remainder of the tongue. Since the hyoid bone obscures the tongue root, an

ultrasound image of the motion required to produce these multiphonics cannot be captured. However, the motion can be observed externally. While making this adjustment, the muscular and skeletal structures in the upper throat region can be seen moving upwards. It is important to note that the sensation felt when making this adjustment is mostly perceived in the throat region. As such, when attempting to make this adjustment, thinking about “constricting, tightening, or closing the throat,” and making adjustments to the throat can yield better success than attempting to actively manipulate the tongue. It is also important to note that a few multiphonics produced using **Strategy D** can also be produced using **Strategy A** or **B**, while some multiphonics produced using **Strategy A** or **B** can be produced using **Strategy D**. The assigned strategy is the more effective and consistent strategy based on empirical experience from the data collection procedure.

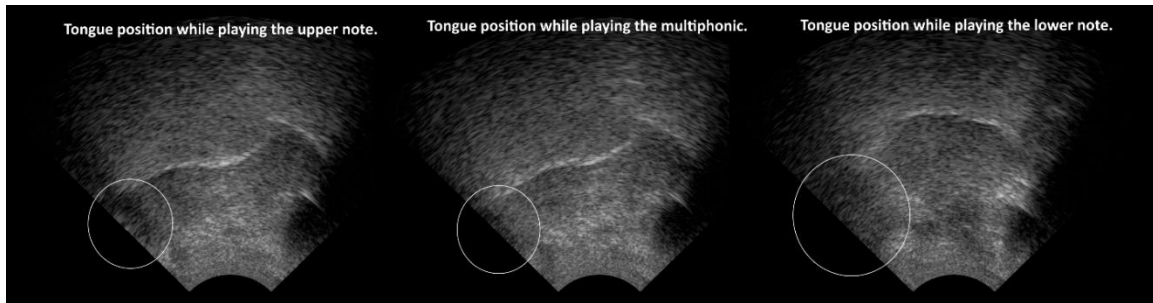


Figure 17. Ultrasound images of the tongue while playing a multiphonic produced using Strategy D (A-flat4 and F-sharp6). The images for the tongue position playing the upper note and the tongue position playing the multiphonic are relatively unchanged when overlaid. However, the hyoid bone shadow is moved further back. Since the transducer is fixed with the ultrasound probe headset, this suggests a change in the muscular and skeletal structures as mentioned.

Every multiphonic was played by making only perceptible adjustments to voicing during the current study. However, in performance, voicing adjustments in combination with embouchure and air stream adjustments may yield a higher success rate. It is important to note that drastic embouchure force changes can have a large impact on the

pitch of the multiphonic and should be avoided when possible. Although pitches may differ between equipment and players, the resulting pitches in every multiphonic should be the same pitch as when played individually using the multiphonic fingerings, unless intentionally altered.

CHAPTER 9

DISCUSSION

The main objectives of this study were to: (1) compile an updated multiphonic catalog, (2) organize the catalog by fingering to facilitate cross referencing with other resources, (3) determine and indicate production strategies for every multiphonic in the new catalog to help performers learn to produce individual multiphonics. To meet these objectives, an updated catalog of 604 dyad multiphonics using 358 unique fingering combinations organized by pitch as well as fingering was compiled. Every multiphonic in the catalog was assigned a production strategy determined over 20 trials and informed perception using ultrasound imaging.

The current multiphonic catalog serves as a resource for both composers and performers. For composers, it provides a large number of multiphonics with a variety of pitch combinations and timbres to suit their compositional needs. For performers, it provides a large number of possible alternatives when confronted by a multiphonic in repertoire that does not work using their equipment and the provided fingering. Since a large number of multiphonics in this catalog have notes within a semi-tone of another multiphonic, especially in the clarion or upper chalumeau range, performers can use this catalog to experiment with different multiphonics to realize pitch combinations indicated by composers. This document also provides information regarding multiphonics acoustics, which may not only help composers and performers understand the limitations of multiphonics, but can also inspire new possibilities for the use of multiphonics in compositions and performances.

This catalog includes information on how to produce every multiphonic and aims to help performers learn to produce multiphonics they encounter in repertoire. As such, it is inevitable that performers will seek specific multiphonics they have encountered in repertoire in this catalog. However, pitches notated by composers may be different than those notated in this catalog, since composers may consult different resources when notating multiphonics. In the case of discrepancies between pitches notated by the composer and pitches notated in this catalog, attempting to find the multiphonic with the same fingering based on its notated pitches can become tedious, frustrating, and time consuming. As such, inventing an organizational system based on fingering is important for creating a positive experience for the catalog end user. With the binary fingering system, any multiphonic can be located easily in the catalog based on its fingering. Although the binary fingering system can be overwhelming and confusing initially, the system can become intuitive once the user is comfortable translating between graphic fingerings and binary fingerings.

The binary fingering system can be adapted for other studies and catalogs as well. It can also be adapted for any instrument, first by identifying a binary number with the same number of digits as the number of keys on the instrument in question, then by mapping each key of said instrument to the digits of the binary number, and finally using the numbers 0 and 1 to indicate undepressed and depressed keys as demonstrated in Chapter 5 “Multiphonic Catalog Organized by Fingering.” Also, unconventional fingerings are frequently used in various extended techniques. This fingering system provides a method of expressing any given fingering without confusion. Although graphic notations are probably more easily deciphered, it may not always be convenient

to express fingerings using such notation. In situations where using graphic notations is inconvenient, the binary fingering provides an alternative method. Additionally, compiling an updated catalog in the future is inevitable, since the catalog compiled as part of the current study is not a complete catalog of every existing multiphonic, and more multiphonic possibilities may be discovered. In the process of updating this catalog, multiphonics not cataloged already can be easily identified and added by consulting the catalog organized by fingerings. Harry Sparnaay published a multiphonic catalog organized by fingering,⁴⁵ though the organizational method is not explained and not easily decipherable from reading the catalog. Sarah Watts seems to use a similar organizational method as Sparnaay in an unpublished sketchbook to help identify uncharted multiphonics, though Watts' published catalog is organized by pitch.⁴⁶

One of the more difficult components of the current study is to reliably determine the voicing adjustment when producing multiphonics. To maximize precision and repeatability, the author conducted twenty trials and used ultrasound imaging to make informed decisions regarding tongue motion. However, this study is only concerned with investigating tongue motion during multiphonic production and does not consider other physiological changes such as adjustments to embouchure force and air pressure, which are also factors that may influence multiphonic production.⁴⁷ In this study, to reduce the influence of embouchure force and air pressure changes on determining multiphonic production strategies, the author made perceptible adjustments only to the tongue throughout the investigative process. However, non-perceptible adjustments to

⁴⁵ Watts, *Spectral Immersions*, 15.

⁴⁶ Ibid., 92, 166-227.

⁴⁷ Sparnaay, *The Bass Clarinet*, 141.

embouchure force or air pressure may have influenced the production strategies, since these two variables were not measured. The four production strategies identified in this study are:

- A. Lowering the back of the tongue while sustaining the upper note;
- B. Raising the back of the tongue while sustaining the upper note;
- C. Changing the tongue position to that of the lower while sustaining the upper note;
- D. Raising the root of the tongue (a sensation similar to constricting the throat) while sustaining the upper note.

During the ultrasound imaging process, the ultrasound transducer was placed submentally to examine the midsagittal plane of the tongue. Four production strategies were identified in the current study to facilitate learning multiphonics found in this catalog. Although other strategies of production may exist, production of multiphonics in this catalog were distilled to four strategies for simplicity.

Each multiphonic was produced by altering the tongue position in one of four ways. Although measuring the amount of alteration required to produce each multiphonic is possible, as demonstrated in Chapter 8 “Multiphonic Production Strategies” to analyze minute tongue motion, it was not necessary for the majority of the multiphonics. The *direction* the tongue moved to produce the multiphonics is likely more important than *how far* the tongue moved. Physiological differences between each individual may lead to variations in the amount of alteration needed; however, the direction of movement is similar, if not identical in most cases. Additionally, the same alterations to tongue position is applied to every multiphonic with the same production strategy, but each multiphonic requires a different amount of alteration. As such, including specific

measurements of how far the tongue moved in general instructions intended to describe entire groups of multiphonics seems unnecessary.

Since this study is intended to help performers learn how to produce multiphonics, it originally intended to explain voicing starting from very basic manipulations such as pitch manipulation. However, considering the demographic of players likely to encounter multiphonics in repertoire—professional clarinetists and advanced students—including basic information on voicing manipulation in this study was deemed beyond its scope. Therefore, the reader is expected to know how to bend pitch or play different overtones of a given fingering. In rare cases where the player using this catalog is unfamiliar with voicing manipulation already, information is readily available and easily accessible, such as in method books or through working with private teachers. A few examples of method books that mention altering tongue position to affect pitch, register, and tone include: *Extreme Clarinet* by Joshua Gardner and Eric Hansen; *The Clarinet Doctor* by Howard Klug; *Clarinet secrets: 52 Performance Strategies for the Advanced Clarinetist* by Michele Gingras; and *The Art of Clarinet Playing* by Keith Stein, among others.

To evaluate the effectiveness of the multiphonic production strategies identified during the current study, eight test subjects' tongue positions while performing 10 multiphonics were observed using ultrasound imaging. While most subjects were able to perform all of the multiphonics, some subjects had much more difficulty than others when producing some of the multiphonics, which was expected. An interesting result, though not completely unexpected, is that the subjects most successful in learning the multiphonics were not necessarily the most experienced performers. The subjects that were able to produce every multiphonic with little difficulty were subjects F, G, and H.

Of these three subjects, only subject H indicated extensive experience with multiphonics, while subjects F and G only have minimal exposure to multiphonics. Additionally, subject D, who has indicated extensive experience with multiphonics, struggled to produce many of the multiphonics. Subject D approached the multiphonic from the bottom notes, contrary to the provided instructions. Of the eight test subjects, three did not use the provided instructions, two used a combination of the provided instructions and previous experience, and three used the provided instructions. Interestingly, of the three test subjects who had little difficulty producing every multiphonic during the ultrasound imaging examination (subjects F, G, and H), two used the instructions, while the remaining subject did not use the instructions but has indicated extensive experience in multiphonic production. Of the subjects who used the instructions when learning the multiphonics, most reported that they found the provided instructions helpful in the learning process.

Further examination of ultrasound images captured for each subject provided additional insight on multiphonic production. Each subject displayed a unique tongue shape when performing the same task. However, when comparing the alterations each subject made to produce each multiphonic, most subjects showed similar voicing adjustments, and the adjustments were consistent with the findings of this study, despite the unique tongue shapes. The difference in tongue shapes are most evident when comparing Subjects G and H playing multiphonic 8 (found in Appendix C on page 127). While the tongue shapes of these two subjects are drastically different when playing the upper note, multiphonic, and lower note, neither subject had difficulty producing the multiphonic or its individual pitches. Multiphonic 8 is produced using **Strategy C**, where

the voicing to produce the multiphonic is an intermediate of the voicings to produce the upper and lower notes, and each subject demonstrated a tongue motion similar to the indicated production strategy.

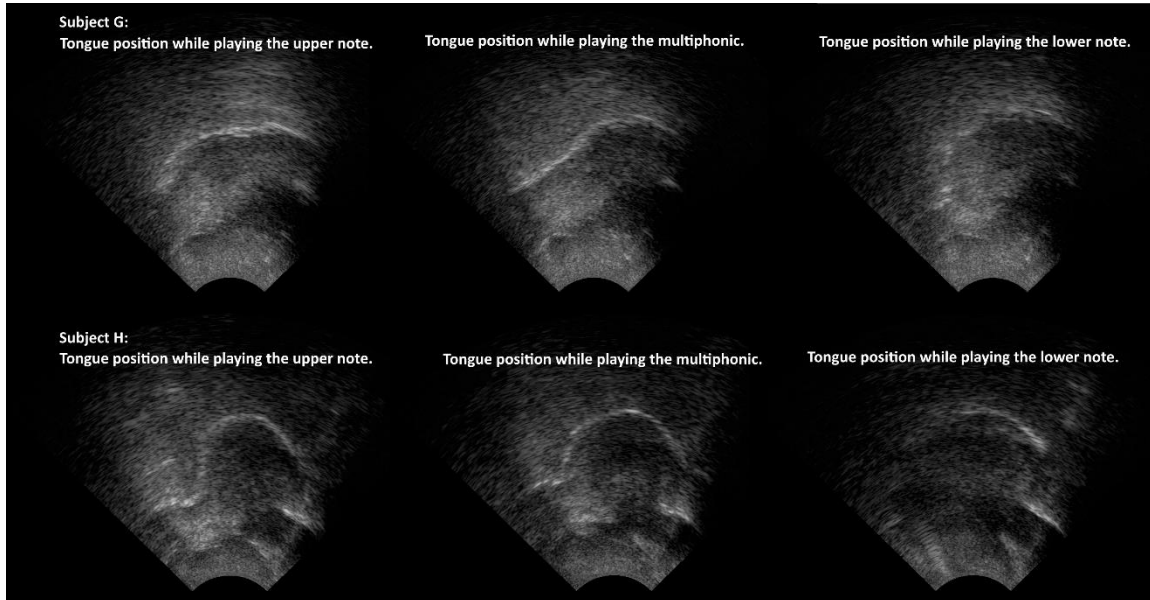


Figure 18. Ultrasound images comparing tongue positions of Subjects G and H playing multiphonic number 8.

As mentioned in Chapter 8, multiphonic production strategies detailed in this document are not exhaustive. Subjects showing voicing adjustments different from the indicated strategy for producing the multiphonic are likely using a different production strategy and this discrepancy should not be used to discredit the indicated production strategies, since these strategies were effective for other subjects.

Although the current study only included a small sample size, the feedback received from the test subjects and the collected data both validate the findings of this study. The results provide information for learning how to produce a wide range of multiphonics. However, it must be emphasized that these strategies are aimed to assist *learning* the correct tongue position for producing multiphonics and not the strategies for

producing multiphonics in performance. To improve the reliability and successful production of multiphonics in performance, the performer must practice forming the correct voicing configuration without utilizing the process described in this study until it can be consistently repeated in the context of the music. It is worth mentioning that proficiency in clarinet performance does not equate to proficiency in multiphonic production, since multiphonic production requires manipulation of the voicing mechanisms in ways uncharacteristic of conventional clarinet playing. Other factors may also affect the execution of multiphonics, such as equipment used, fatigue level, or even the water content of the reed as it changes throughout the performance.⁴⁸

⁴⁸ Ibid., 140.

CHAPTER 10

CONCLUSION

The results of this study provide pedagogical and performance insight into multiphonic production mechanics. Each multiphonic in the catalog compiled for this study can be produced by using one of four production strategies. These production strategies serve as tools for finding the correct voicing to produce the multiphonic and may require slight modification depending on the player. They are intended as practice tools to facilitate practice sessions and voicing experimentation; however, other strategies may exist. To successfully incorporate multiphonics in performance, the performer must practice acquiring the correct voicing immediately, without “hunting” for its proper configuration.

The study also used ultrasound imaging to investigate tongue motion and to help reinforce and correct subjective perception of the tongue during clarinet multiphonic performance. The ultrasound tongue images serve as important visual feedback to help clarify and describe performance tongue motion, especially regarding multiphonics. The ultrasound images also facilitate a better understanding of tongue motion and how pitch and register can be controlled by moving different parts of the tongue. Gaining increased awareness, understanding, and control of tongue motion is not only crucial to playing multiphonics but can also improve conventional clarinet playing technique.⁴⁹

The ultrasound imaging protocol used in this study was adapted from previous research regarding clarinet multiple articulation by Joshua Gardner. This study further demonstrates the effectiveness of this protocol as a research method for examining the

⁴⁹ Mandat, “Expanding Timbral Flexibility through Multiphonics,” 27-30.

behavior of a player's tongue during clarinet performance. Other potential uses for this protocol may exist, not only for the improvement of clarinet pedagogy and performance but also for other wind instruments. One possible future study is to provide ultrasound images of every multiphonic in this catalog to minimize subjective perception and description regarding multiphonic production strategies. Another interesting study would be to examine tongue motion when producing multiphonics on other instruments such as bass clarinet, E-flat clarinet, instruments of the saxophone family, or other wind instruments. The current research procedures and investigative process can also be modified to examine voicing in other aspects of clarinet performance to provide insight on voicing control and manipulation which could be pedagogically valuable to clarinetists of all levels and experience.

The catalog compiled during this research will also be expanded in the future, consulting printed and online catalogs not examined in the present document. Details such as dynamic flexibility and timbral quality of each multiphonic will also be included in the future. Future updates to this catalog will add audio recordings and ultrasound videos of the tongue when producing every multiphonic.

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APPENDIX A

MULTIPHONIC CATALOG ORGANIZED BY PITCH

Multiphonic production strategy and the difficulty of each individual multiphonic is indicated below each multiphonic. The letters indicate the production strategy as detailed in the Chapter 8 “Multiphonic Production Strategies.” The numbers indicate the difficulty level of the multiphonic as detailed in the Chapter 7 “Research Procedures.”

A - 4 A - 2 A - 2 A - 2 A - 3 A - 4

A - 5 A - 4 A - 2 A - 2 A - 3 A - 4

A - 5 A - 4 A - 2 A - 3 A - 3 A - 4

19

A - 2 A - 2 A - 4 A - 5 A - 4 A - 3

25

A - 2 A - 2 A - 3 A - 3 A - 5 A - 4

31

A - 5 A - 1 A - 3 A - 4 A - 2 A - 3

37

A - 3 A - 4 A - 4 A - 4 A - 3 A - 2

43

A - 2 A - 2 A - 2 A - 1 A - 4 A - 3

49

A - 3 A - 3 A - 4 A - 4 A - 4 A - 5

55

A - 3 A - 3 A - 3 A - 4 A - 3 A - 3

61

A - 2 A - 2 A - 3 A - 4 A - 4 A - 5

67

A - 5 A - 5 A - 3 A - 2 A - 4 A - 4

73

A - 5 A - 1 A - 1 A - 1 A - 2 A - 3

79

A - 2 A - 2 A - 2 A - 4 A - 2 A - 2

85

A - 2 A - 2 A - 2 A - 1 A - 3 A - 1

91

A - 1 A - 2 A - 2 A - 2 A - 2 A - 2

97

A - 2 A - 5 A - 2 A - 3 A - 5 A - 2

103

A - 2 A - 2 A - 2 A - 2 A - 2 A - 2

109

A - 3 B - 3 B - 2 B - 2 B - 2 A - 2

115

B - 3 A - 4 B - 3 B - 4 B - 2 A - 1

A - 1 B - 1 A - 1 A - 1 B - 1 A - 3

127

A - 1 A - 2 B - 3 A - 3 A - 2 B - 3

133

A - 3 A - 3 B - 4 B - 3 A - 4 B - 2



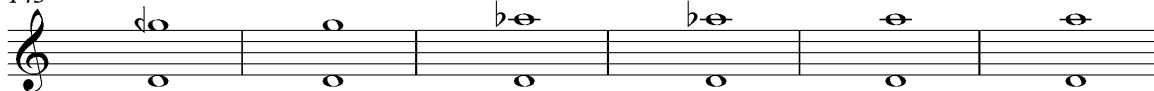
139



A - 3 B - 2 B - 2 B - 2 A - 2 B - 3



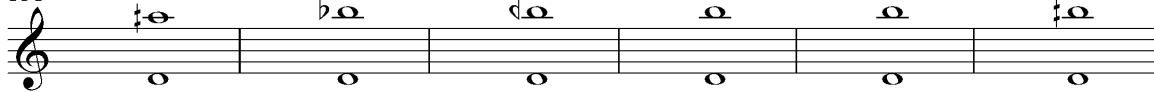
145



B - 4 B - 3 B - 4 A - 5 A - 2 A - 2



151



A - 3 B - 3 A - 2 B - 2 A - 1 B - 1



157



A - 1 A - 2 B - 2 B - 1 B - 2 B - 1

163

A - 3 A - 3 B - 4 A - 4 B - 3 B - 3

169

B - 3 B - 2 B - 3 B - 3 A - 3 B - 4

175

B - 4 B - 3 A - 3 A - 3 A - 3 A - 3

181

A - 3 B - 2 B - 2 A - 1 A - 1 A - 1

Hand position diagrams for measures 187-192. Measure 187 shows a right hand with fingers 1-4 on a single key and thumb on a lower key. Measures 188-192 show various combinations of fingers on multiple keys, with some keys marked with sharps or flats.

187
A - 1 B - 4 A - 3 A - 4 B - 4 B - 2

Hand position diagrams for measures 193-198. Measure 193 shows a right hand with fingers 2-4 on a single key and thumb on a lower key. Measures 194-198 show various combinations of fingers on multiple keys, with some keys marked with sharps or flats.

193
B - 2 B - 3 B - 3 B - 4 B - 3 B - 4

Hand position diagrams for measures 199-204. Measure 199 shows a right hand with fingers 2-4 on a single key and thumb on a lower key. Measures 200-204 show various combinations of fingers on multiple keys, with some keys marked with sharps or flats.

199
B - 2 B - 3 B - 2 B - 2 A - 3 A - 3

Hand position diagrams for measures 205-210. Measure 205 shows a right hand with fingers 3-4 on a single key and thumb on a lower key. Measures 206-210 show various combinations of fingers on multiple keys, with some keys marked with sharps or flats.

205
A - 3 A - 2 B - 3 B - 3 B - 3 B - 3

211

B - 3 A - 3 A - 3 A - 3 A - 4 A - 4

217

B - 4 B - 4 A - 4 A - 4 A - 4 A - 5

223

A - 5 B - 3 B - 2 B - 2 B - 2 B - 3

229

A - 3 B - 2 A - 3 B - 3 B - 2 B - 2

Hand position diagrams for measures 235-240. Each diagram shows a vertical column of six circles representing fingers. Filled circles indicate fingers that are pressed down, while open circles indicate fingers that are lifted. Measure 235 shows a sequence of finger presses: index (1), middle (2), ring (3), and thumb (4). Measure 236 shows index (1), middle (2), ring (3), and thumb (4). Measure 237 shows index (1), middle (2), ring (3), and thumb (4). Measure 238 shows index (1), middle (2), ring (3), and thumb (4). Measure 239 shows index (1), middle (2), ring (3), and thumb (4). Measure 240 shows index (1), middle (2), ring (3), and thumb (4).

235

A - 3 B - 4 A - 3 B - 2 A - 2 A - 2

Hand position diagrams for measures 241-246. Each diagram shows a vertical column of six circles representing fingers. Filled circles indicate fingers that are pressed down, while open circles indicate fingers that are lifted. Measure 241 shows a sequence of finger presses: index (1), middle (2), ring (3), and thumb (4). Measure 242 shows index (1), middle (2), ring (3), and thumb (4). Measure 243 shows index (1), middle (2), ring (3), and thumb (4). Measure 244 shows index (1), middle (2), ring (3), and thumb (4). Measure 245 shows index (1), middle (2), ring (3), and thumb (4). Measure 246 shows index (1), middle (2), ring (3), and thumb (4).

241

B - 2 B - 2 B - 3 B - 2 A - 3 B - 3

Hand position diagrams for measures 247-252. Each diagram shows a vertical column of six circles representing fingers. Filled circles indicate fingers that are pressed down, while open circles indicate fingers that are lifted. Measure 247 shows a sequence of finger presses: index (1), middle (2), ring (3), and thumb (4). Measure 248 shows index (1), middle (2), ring (3), and thumb (4). Measure 249 shows index (1), middle (2), ring (3), and thumb (4). Measure 250 shows index (1), middle (2), ring (3), and thumb (4). Measure 251 shows index (1), middle (2), ring (3), and thumb (4). Measure 252 shows index (1), middle (2), ring (3), and thumb (4).

247

B - 1 A - 3 B - 4 A - 4 B - 2 B - 2

Hand position diagrams for measures 253-258. Each diagram shows a vertical column of six circles representing fingers. Filled circles indicate fingers that are pressed down, while open circles indicate fingers that are lifted. Measure 253 shows a sequence of finger presses: index (1), middle (2), ring (3), and thumb (4). Measure 254 shows index (1), middle (2), ring (3), and thumb (4). Measure 255 shows index (1), middle (2), ring (3), and thumb (4). Measure 256 shows index (1), middle (2), ring (3), and thumb (4). Measure 257 shows index (1), middle (2), ring (3), and thumb (4). Measure 258 shows index (1), middle (2), ring (3), and thumb (4).

253

B - 3 A - 2 A - 3 A - 2 B - 3 B - 4

259

B - 2 B - 2 B - 2 B - 2 B - 2 B - 2

265

B - 2 B - 2 B - 3 B - 3 A - 3 B - 3

271

B - 3 B - 3 B - 2 B - 1 B - 1 B - 4

277

B - 2 B - 3 B - 4 B - 2 B - 3 B - 3

283

B - 3 B - 2 B - 3 B - 3 B - 2 A - 4

289

B - 3 B - 3 B - 2 B - 2 B - 2 B - 2

295

A - 2 B - 3 B - 2 B - 3 A - 3 B - 3

301

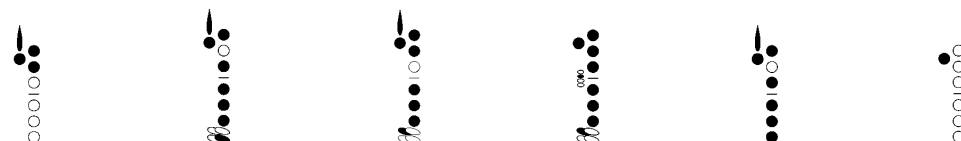
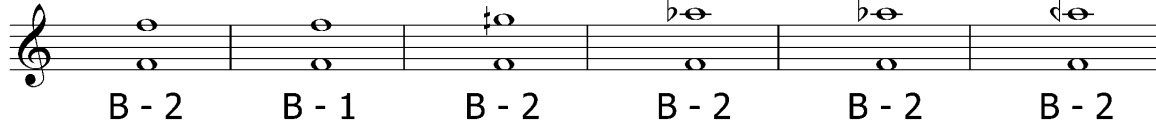
A - 3 A - 3 B - 2 B - 3 A - 3 B - 1



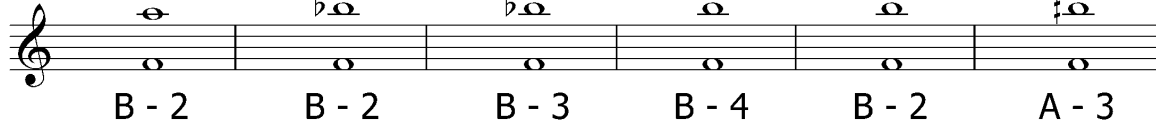
307



313



319



325



331

B - 1 B - 1 A - 2 A - 1 B - 2 B - 2

337

A - 4 B - 3 A - 5 A - 4 B - 3 B - 2

343

B - 2 B - 3 B - 3 B - 3 B - 2 B - 2

349

B - 2 A - 2 A - 2 A - 2 A - 3 B - 2

355

A - 2 B - 2 B - 2 B - 2 B - 2 B - 2

361

B - 2 A - 2 A - 3 B - 3 B - 3 B - 3

367

A - 4 B - 3 A - 4 A - 3 B - 2 B - 2

373


B - 3 B - 3 B - 3 B - 2 B - 2 B - 2

Hand position diagrams for measures 379-384. Each diagram shows a hand with fingers numbered 1-5. Measure 379: B-3, B-2, B-2, B-2, B-2, B-4. Measure 380: B-3, B-2, B-2, B-2, B-2, B-4. Measure 381: B-3, B-2, B-2, B-2, B-2, B-4. Measure 382: B-3, B-2, B-2, B-2, B-2, B-4. Measure 383: B-3, B-2, B-2, B-2, B-2, B-4. Measure 384: B-3, B-2, B-2, B-2, B-2, B-4.

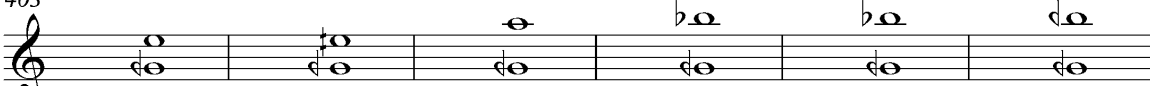
Hand position diagrams for measures 385-390. Each diagram shows a hand with fingers numbered 1-5. Measure 385: A-3, A-2, A-3, A-2, B-2, B-3. Measure 386: A-3, A-2, A-3, A-2, B-2, B-3. Measure 387: A-3, A-2, A-3, A-2, B-2, B-3. Measure 388: A-3, A-2, A-3, A-2, B-2, B-3. Measure 389: A-3, A-2, A-3, A-2, B-2, B-3. Measure 390: A-3, A-2, A-3, A-2, B-2, B-3.

Hand position diagrams for measures 391-396. Each diagram shows a hand with fingers numbered 1-5. Measure 391: B-2, B-2, D-3, B-3, B-3, A-3. Measure 392: B-2, B-2, D-3, B-3, B-3, A-3. Measure 393: B-2, B-2, D-3, B-3, B-3, A-3. Measure 394: B-2, B-2, D-3, B-3, B-3, A-3. Measure 395: B-2, B-2, D-3, B-3, B-3, A-3. Measure 396: B-2, B-2, D-3, B-3, B-3, A-3.


Hand position diagrams for measures 397-402. Each diagram shows a hand with fingers numbered 1-5. Measure 397: D-3, B-3, A-4, A-2, B-2, B-2. Measure 398: D-3, B-3, A-4, A-2, B-2, B-2. Measure 399: D-3, B-3, A-4, A-2, B-2, B-2. Measure 400: D-3, B-3, A-4, A-2, B-2, B-2. Measure 401: D-3, B-3, A-4, A-2, B-2, B-2. Measure 402: D-3, B-3, A-4, A-2, B-2, B-2.



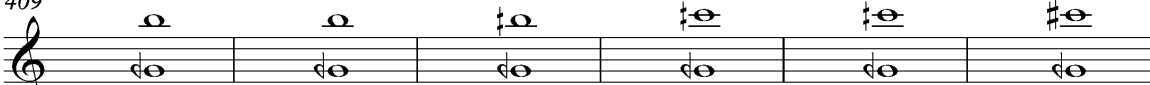
403




B - 2 B - 2 B - 2 B - 2 B - 2 B - 2




409




B - 2 B - 2 B - 2 A - 2 B - 2 A - 2




415



B - 2 B - 1 B - 2 B - 2 B - 2 B - 3



421



D - 3 D - 3 D - 3 B - 3 D - 3 D - 3

427

B - 3 B - 3 A - 2 B - 3 B - 3 B - 3

433

A - 3 B - 3 B - 3 B - 3 B - 2 B - 2

439

B - 2 B - 2 A - 3 A - 3 A - 2 B - 2

445

B - 2 B - 3 B - 2 B - 3 A - 3 B - 3

451

A - 4 B - 3 A - 5 A - 4 B - 3 A - 4


B - 3 B - 2 B - 1 B - 1 B - 2 B - 3

463


B - 3 A - 3 B - 1 B - 3 A - 1 B - 2

469


A - 3 A - 3 A - 3 B - 3 B - 5 B - 1




475




B - 2 B - 1 B - 2 B - 2 B - 2 B - 2



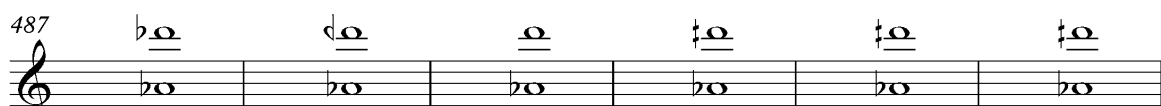
481




B - 2 B - 2 A - 2 B - 2 B - 3 B - 3



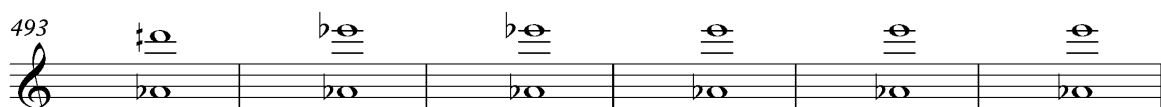
487



B - 2 A - 3 B - 3 A - 4 A - 3 B - 3



493



B - 3 A - 3 A - 2 B - 3 B - 3 B - 3

499 B - 2 B - 4 A - 3 B - 2 D - 3 D - 3

505 D - 3 A - 3 D - 3 B - 3 D - 5 A - 5

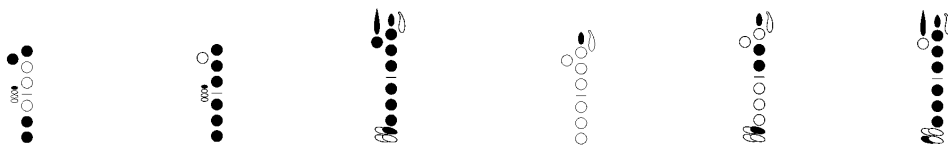
511 B - 4 A - 5 A - 3 A - 3 B - 3 B - 2

517 B - 2 A - 2 B - 2 B - 3 B - 4 A - 4



523

A - 4 A - 3 A - 4 A - 3 A - 3 B - 3



529

B - 2 A - 3 A - 3 A - 3 A - 3 A - 3



535

A - 3 B - 3 A - 3 D - 3 B - 3 A - 5



541

B - 3 A - 3 B - 3 A - 3 B - 3 D - 3

547

B - 2 A - 3 B - 3 A - 4 A - 4

552

A - 3 B - 2 B - 2 A - 2 B - 4 A - 4

558

A - 4 A - 4 B - 3 B - 2 A - 2 B - 2

564

A - 5 A - 3 B - 2 B - 2 C - 5 A - 2

570

B - 3 B - 2 A - 3 A - 4 A - 4 C - 4

576

D - 3 C - 4 A - 4 C - 5 A - 4 A - 4

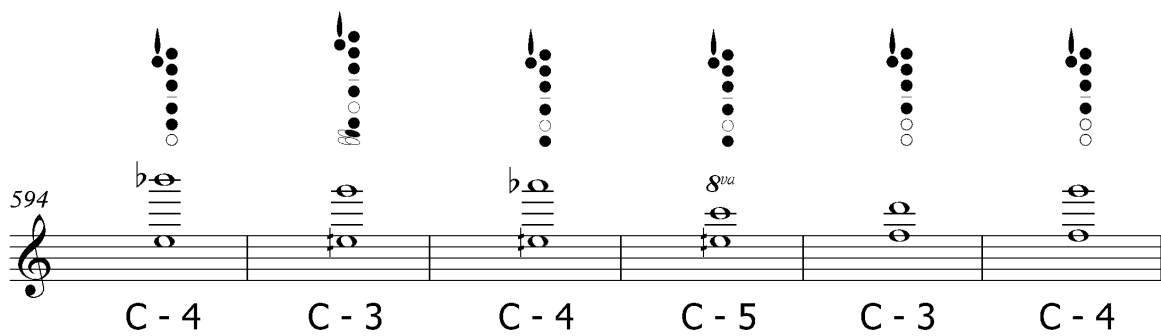
582

C - 4 A - 3 A - 3 A - 3 C - 2 A - 2

588

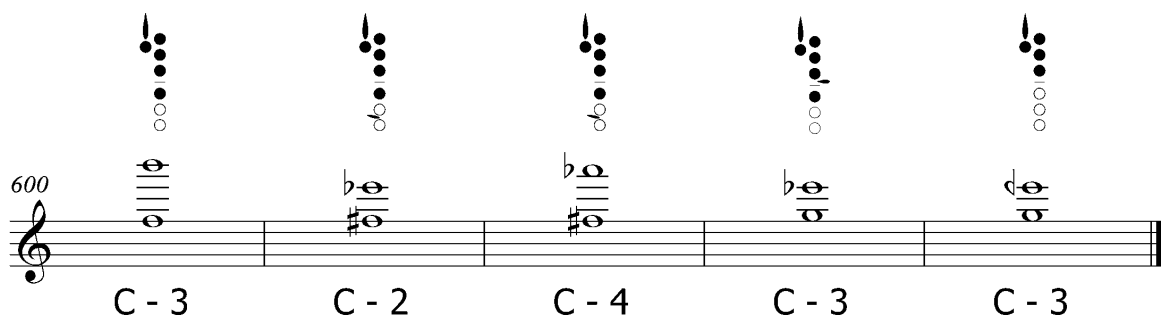
A - 4 C - 3 A - 3 A - 3 C - 3 C - 3

594



C - 4 C - 3 C - 4 C - 5 C - 3 C - 4

600



C - 3 C - 2 C - 4 C - 3 C - 3

APPENDIX B

MULTIPHONIC CATALOG ORGANIZED BY FINGERING

Multiphonic production strategy and the difficulty of each individual multiphonic is indicated below each multiphonic. The letters indicate the production strategy as detailed in the Chapter 8 “Multiphonic Production Strategies.” The numbers indicate the difficulty level of the multiphonic as detailed in the Chapter 7 “Research Procedures.”

The organizational method for this catalog is detailed in the Chapter 5 “Organizing Multiphonic Catalog by Fingering”. The binary fingering of the first and last multiphonic on each page is also indicated at the top of the page.

00 00 000 00 0000 – 000 0 0000

00 00 111 00 0000 – 110 0 0100

A - 3 A - 4 A - 3 A - 3 A - 3 A - 4

7

A - 3 A - 3 A - 3 A - 2 A - 2 A - 4

13

A - 1 A - 2 A - 2 A - 5 A - 3 A - 3

00 00 111 00 0000 – 111 0 0000
 01 00 001 00 0000 – 110 0 0000

19 A - 2 A - 3 A - 3 A - 3 A - 2 A - 3

25 A - 4 A - 3 A - 2 A - 2 A - 4 A - 5

31 A - 5 A - 3 A - 3 A - 4 A - 3 A - 5

37 A - 3 A - 4 A - 3 A - 4 A - 4 B - 3

01 00 001 00 0000 – 111 0 1000
 01 00 011 00 0000 – 011 0 1000

43

B - 3 B - 3 B - 1 B - 2 B - 3 B - 3

49

B - 3 B - 3 B - 3 B - 3 B - 3 B - 1

55

B - 2 A - 3 A - 4 A - 3 A - 3 A - 2

61

A - 3 A - 2 A - 2 A - 3 A - 3 A - 2

01 00 011 00 0000 – 100 0 0000
 01 00 011 00 0000 – 111 0 1000

67

B - 3 B - 3 B - 2 B - 3 B - 4 B - 3

73

B - 4 B - 3 B - 2 B - 2 B - 4 B - 2

79

B - 4 B - 4 B - 4 B - 2 B - 2 B - 3

85

B - 2 B - 3 B - 1 B - 3 B - 3 B - 4

01 00 011 00 0000 – 111 0 1000
 01 00 100 00 0100 – 011 0 0000

91

B - 2 B - 4 B - 1 B - 3 B - 2 B - 3

97

B - 2 B - 3 B - 3 B - 2 B - 3 B - 2

103

B - 2 B - 3 B - 1 B - 3 A - 3 A - 4

109

A - 4 A - 4 A - 4 A - 3 A - 2 A - 3

01 00 100 00 1000 – 011 0 0000
 01 00 101 00 0100 – 111 0 0000

115

B - 2 B - 3 A - 3 A - 3 A - 1 A - 3

121

A - 3 A - 1 A - 3 A - 1 A - 3 A - 1

127

A - 2 A - 1 A - 3 A - 1 A - 3 A - 3

133

A - 2 A - 4 A - 3 A - 1 A - 4 B - 3

01 00 101 01 0000 – 111 0 0000
 01 00 110 00 1000 – 000 0 0000

139

A - 2 A - 2 A - 3 A - 3 A - 1 A - 2

145

A - 2 A - 3 A - 1 A - 3 A - 1 A - 1

151

A - 3 A - 3 A - 3 A - 5 A - 5 A - 4

157

A - 3 A - 3 A - 4 A - 3 A - 4 B - 2

01 00 110 01 0000 – 111 0 0000
 01 00 111 00 0000 – 100 1 1000

163

B - 4 B - 3 A - 3 A - 3 A - 2 A - 5

169

A - 4 A - 5 A - 5 A - 3 A - 3 A - 4

175

A - 2 A - 5 A - 2 A - 4 A - 5 A - 3

181

A - 3 A - 4 A - 3 A - 3 A - 3 A - 2

01 00 111 00 0000 – 100 1 1000
 01 00 111 00 0000 – 110 0 0100

187

A - 4 A - 2 A - 3 A - 4 A - 5 A - 4

193

A - 3 A - 2 A - 3 A - 4 A - 4 A - 1

199

A - 2 A - 3 A - 2 A - 4 A - 4 A - 4

205

A - 2 A - 3 A - 4 A - 1 A - 3 A - 3

01 00 111 00 0000 – 111 0 0000
 01 00 111 00 0000 – 111 0 1000

211

Notes: C4, D4, E4, F4, G4, A4

Fingerings: 1, 2, 3, 4, 5, 1

Interval labels: A - 4, A - 2, A - 2, A - 4, A - 5, A - 4

217

Notes: C4, D4, E4, F4, G4, A4

Fingerings: 1, 2, 3, 4, 5, 1

Interval labels: A - 4, A - 2, A - 2, A - 2, A - 3, A - 4

223

Notes: C4, D4, E4, F4, G4, A4

Fingerings: 1, 2, 3, 4, 5, 1

Interval labels: A - 5, A - 4, A - 2, A - 3, A - 3, A - 4

229

Notes: C4, D4, E4, F4, G4, A4

Fingerings: 1, 2, 3, 4, 5, 1

Interval labels: A - 2, A - 2, A - 3, A - 4, A - 5, A - 3

01 00 111 00 0000 – 111 0 1000
 01 00 111 00 0001 – 111 0 1000

235

A - 2 A - 3 A - 5 A - 5 A - 2 A - 3

241

A - 4 B - 3 A - 3 B - 4 B - 3 B - 1

247

B - 2 B - 1 B - 3 B - 3 B - 2 B - 2

253

B - 3 B - 3 B - 1 B - 3 B - 2 B - 3

01 00 111 00 0100 – 000 0 0000
 01 00 111 01 0000 – 010 0 0000



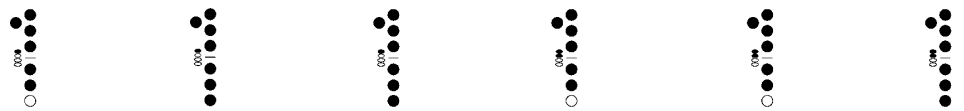
259

B - 3 B - 3 B - 2 B - 2 B - 2 B - 4



265

B - 2 C - 5 C - 4 B - 3 B - 1 B - 3



271

B - 2 B - 3 C - 2 A - 3 A - 3 A - 3



277

A - 3 A - 3 A - 3 A - 2 A - 4 A - 2

01 00 111 01 0000 – 010 0 0000
 01 00 111 01 0000 – 111 0 0100

283

A - 2 A - 2 A - 2 A - 2 A - 2 A - 2

289

A - 1 A - 2 A - 3 A - 2 A - 2 A - 1

295

A - 2 A - 3 A - 1 A - 2 A - 2 A - 2

301

A - 2 A - 2 A - 1 A - 2 A - 4 A - 1

01 00 111 01 0000 – 111 0 0100
 01 01 111 00 0000 – 000 0 1000

307

A - 2 A - 2 A - 2 A - 1 A - 2 A - 2

313

A - 2 A - 5 A - 2 B - 2 B - 3 B - 1

319

B - 4 B - 2 B - 2 B - 2 B - 2 B - 3

325

B - 3 B - 1 B - 2 B - 2 D - 3 B - 2

01 01 111 00 0000 – 000 0 1000
 01 01 111 01 0000 – 000 0 1000

331

B - 2 B - 2 B - 3 B - 2 B - 3 B - 2

337

B - 2 B - 2 B - 1 B - 2 B - 1 B - 1

343

B - 3 B - 2 B - 2 B - 3 B - 4 B - 3

349

B - 2 B - 3 B - 2 B - 3 B - 3 B - 3

01 01 111 01 0000 – 000 0 1000
 10 00 100 00 0000 – 000 0 0000

355 B - 2 B - 3 A - 3 A - 3 A - 2 A - 3

361 D - 3 B - 1 A - 2 A - 4 A - 2 A - 3

367 B - 2 B - 3 A - 3 C - 5 A - 3 B - 3

373 B - 3 A - 3 A - 4 D - 3 B - 3 B - 3

10 00 100 00 0000 – 000 0 0000
 11 00 000 00 0000 – 100 0 0000

379

B - 4 B - 1 A - 1 A - 3 A - 2 A - 2

385

A - 3 A - 2 A - 2 A - 2 A - 3 A - 4

391

A - 5 A - 4 A - 4 A - 4 A - 3 A - 3

397

A - 4 B - 2 B - 2 B - 2 B - 3 B - 3

11 00 000 00 0000 – 110 0 0000
 11 00 011 00 0000 – 101 0 1000

403

B - 3 B - 2 B - 3 B - 4 B - 2 B - 2

409

B - 2 D - 3 D - 3 B - 2 D - 3 D - 3

415

D - 3 B - 2 B - 3 B - 2 B - 2 B - 1

421

B - 3 D - 3 B - 2 B - 3 B - 2 B - 2

11 00 011 00 0000 – 110 0 0000
 11 00 101 00 0000 – 100 0 0000

427

B - 3 B - 2 B - 3 B - 2 B - 2 B - 2

433

B - 2 B - 3 B - 2 B - 2 B - 3 B - 3

439

B - 2 B - 3 B - 2 B - 2 B - 2 A - 3

445

A - 2 A - 2 A - 2 B - 2 B - 2 B - 1

11 00 101 00 0000 – 110 0 1000
 11 00 110 00 0100 – 011 0 0000

451

B - 3 B - 2 B - 2 B - 3 B - 2 B - 2

457

B - 2 B - 2 B - 2 B - 2 B - 2 B - 2

463

B - 2 B - 1 B - 3 B - 2 B - 2 B - 2

469

B - 3 B - 2 B - 2 B - 2 B - 3 B - 3

11 00 110 00 0100 – 011 0 0000
 11 00 111 00 0000 – 101 0 0001

475

D - 3 B - 2 B - 2 B - 2 C - 3 B - 3

481

B - 3 B - 2 B - 3 B - 2 B - 2 B - 3

487

C - 3 C - 4 C - 3 B - 3 C - 2 C - 4

493

B - 3 B - 2 C - 4 C - 5 B - 2 B - 2

11 00 111 00 0000 – 101 0 0001
 11 00 111 00 0001 – 000 0 0000

499

C - 3 B - 2 B - 3 C - 3 B - 4 C - 3

505

C - 3 C - 4 B - 2 A - 3 A - 2 A - 4

511

A - 2 A - 3 A - 4 A - 4 A - 3 A - 3

517

A - 4 A - 4 A - 3 A - 3 B - 2 B - 3

11 00 111 00 0001 – 000 0 0000
 11 00 111 01 0000 – 110 0 0010

523

B - 3 B - 3 B - 2 B - 3 B - 3 B - 2

529

B - 3 B - 3 B - 2 B - 3 ? - 2 B - 3

535

B - 2 B - 2 B - 2 B - 4 B - 2 B - 2

541

B - 2 B - 4 C - 3 B - 3 B - 2 B - 3

11 00 111 01 0000 – 110 0 0010
 11 01 101 00 0000 – 111 0 0100

547

B - 2 B - 2 B - 2 B - 2 B - 2 B - 3

553

B - 4 B - 3 B - 4 B - 4 B - 2 B - 4

559

B - 2 B - 2 B - 2 B - 2 B - 2 B - 3

565

B - 3 B - 5 B - 3 B - 3 B - 2 B - 3

11 01 110 00 0000 – 111 0 0000
 11 10 100 00 1000 – 011 0 0000

Measures 571-576: Hand position diagrams and musical notation. The diagrams show fingerings for the right hand. The musical notation is in treble clef, showing notes and accidentals for each measure.

571 B - 2 B - 3 D - 3 D - 5 B - 2 B - 2

Measures 577-582: Hand position diagrams and musical notation. The diagrams show fingerings for the right hand. The musical notation is in treble clef, showing notes and accidentals for each measure.

577 D - 3 B - 2 B - 3 B - 2 B - 4 B - 3

Measures 583-588: Hand position diagrams and musical notation. The diagrams show fingerings for the right hand. The musical notation is in treble clef, showing notes and accidentals for each measure.

583 B - 2 B - 2 B - 2 B - 3 B - 2 B - 3

Measures 589-594: Hand position diagrams and musical notation. The diagrams show fingerings for the right hand. The musical notation is in treble clef, showing notes and accidentals for each measure.

589 B - 4 B - 1 B - 3 B - 2 B - 3 C - 4

11 10 100 00 1000 – 011 0 0000
 11 10 111 00 1100 – 111 0 0100

595

C - 4 D - 3 D - 3 A - 4 A - 4

600

A - 3 A - 2 A - 3 A - 3 A - 3

APPENDIX C

MULTIPHONICS AND INSTRUCTIONS FOR TEST SUBJECTS

Multiphonic Test Subject Questionnaire:

List of personal equipment:

Clarinet:

Barrel:

Mouthpiece:

Ligature:

Reed:

Please briefly describe your experience with multiphonics in repertoire:

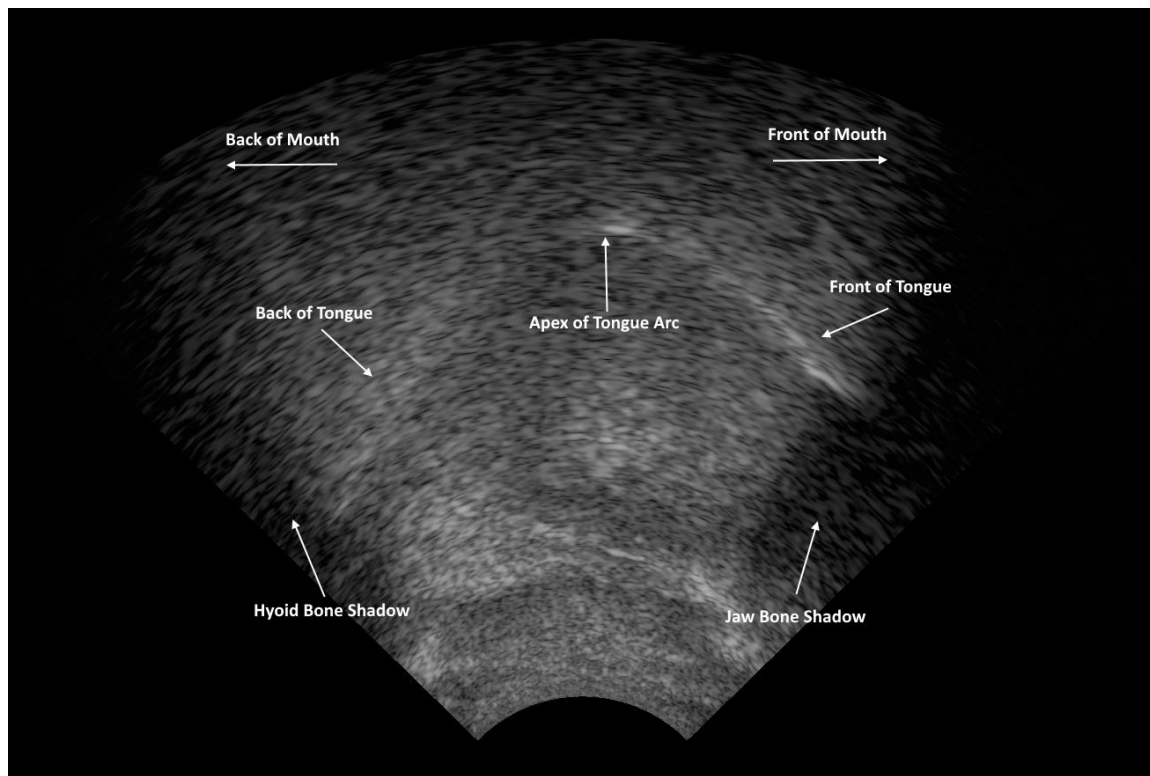
Did you use the provided instructions to help you learn the multiphonics, if yes, were the instructions helpful?

Instructions:

You are provided with an excerpt from the Chapter “Multiphonic Production Strategies” containing the four strategies for producing multiphonics, and 10 multiphonics. You have 5 days to learn to produce these multiphonics. You are encouraged to follow the instructions provided but are not restricted to the strategies described. However, you are not to consult other sources, including but not limited to teachers, the author of this study, other participants of this study, peers, and other resource materials.

Upon arrival at the Performance Physiology Research Laboratory at Arizona State University, you will be fitted to the ultrasound probe headset. You will then be asked to perform the 10 multiphonics while seated and facing away from the ultrasound machine monitor. You will first perform the multiphonics as individual pitches and then as a multiphonic. Ultrasound images will be captured of your tongue position when you play the upper note, lower note, and multiphonic of each task, as well as the resting position of your tongue when not playing. If you wear glasses, you are encouraged to wear contact lenses or memorize the multiphonics, since the ultrasound probe headset may prevent you from wearing your glasses. To maximize image quality, stay hydrated before and during the imaging process.

In the description of multiphonic production strategies, ultrasound images have been included as visual aids. The following is an ultrasound image of the tongue at rest, labelled with areas of interest to help you interpret the images you will encounter later in the written material.



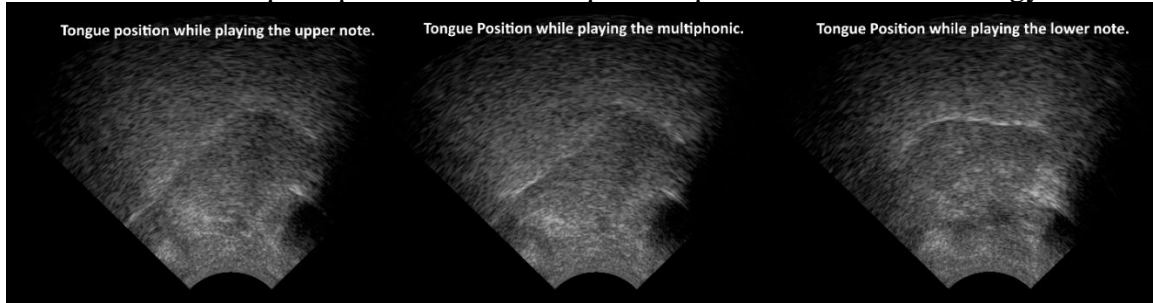
Ultrasound image of the tongue at rest labeled with areas of interest.

Multiphonic Production Strategies:

The correct voicing for producing any multiphonic can be described as an intermediate of the voicings for producing the individual notes of the multiphonic. The performer should attempt to produce the multiphonic after successfully producing the individual pitches of the multiphonic. Through investigations using technology and informed perception over numerous trials, it was found that every multiphonic can be facilitated using one of four production strategies (A, B, C, and D) as indicated in the catalog.

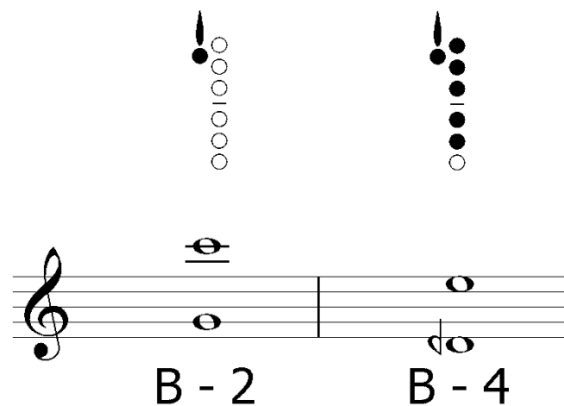
Multiphonics produced using **Strategy A** mostly utilize a fingering that results in a bore configuration likely to produce a pitch in the chalumeau register (e.g., any multiphonic using a conventional fingering for a note in the chalumeau register). To produce these multiphonics, first play the upper note. While sustaining, slowly lower and retract the back part of the tongue while maintaining the tongue position in the middle portion of the tongue until the lower note can be heard in addition to the upper note. The performer can think of relaxing the tongue while sustaining the upper note can facilitate performing the described motion to produce these multiphonics. Multiphonics with larger intervals require smaller but more precise adjustments. This is likely due to voicing having more influence over pitch in higher tessitura, and having less influence over pitch in lower tessitura. As such, the multiphonic voicing is very similar to that of the upper note to facilitate production of the higher pitch, while having minimal effect on the lower note. For some multiphonics with an interval less than a perfect fifth, there is almost no perceptible change in voicing. During the current study, every multiphonic was produced

with only perceptible adjustments to voicing. In practice, a slight decrease in embouchure force and air can help the production of multiphonics produced with this strategy.



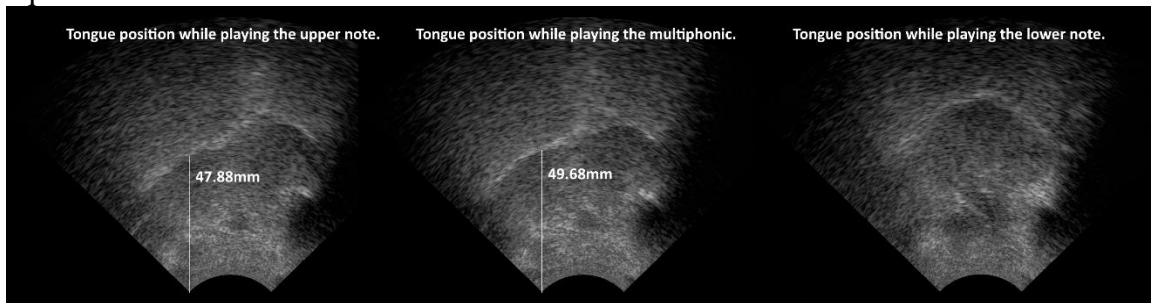
Ultrasound images of the tongue while playing a multiphonic produced using Strategy A. The back of the tongue is lowered while the apex of the tongue arc remains relatively unchanged. Note how the tongue contour for the multiphonic is more similar to the upper note tongue shape than the lower note tongue shape.

Multiphonics produced using **Strategy B** are generally multiphonics that use a fingering involving the register key or an alternate register key while simultaneously producing the fundamental pitch. Some examples of multiphonics in this category include multiphonics using a conventional fingering for a note in the clarion register while producing the clarion pitch as well as a lower pitch. To produce these multiphonics, first play the upper note. While sustaining, raise the back of the tongue until both pitches are audible. The performer can think about trying to touch the ridge dividing the hard and soft palate with the back of the tongue, but moving very slightly, to facilitate performing the action described for this production strategy. Similar to multiphonics produced using **Strategy A**, multiphonics with larger intervals between the notes require smaller but more precise adjustment. Multiphonics produced using **Strategy B** that use bore configurations with longer effective tube lengths are more difficult to produce (especially if the upper note is in the clarion register) than ones that use a shorter effective bore length. For example, the following multiphonics are both produced using **Strategy B**.



Example of two multiphonics produced with Strategy B using different effective tube lengths.

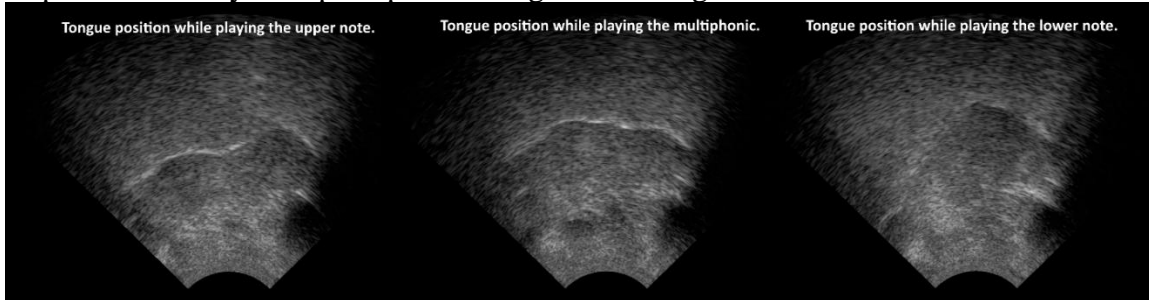
However, the first multiphonic has a difficulty level of 2 while the second multiphonic has a difficulty level of 4. One of the reasons the second multiphonic is more difficult to produce due to the longer effective tube length of the bore configuration, since the lower note is much more difficult to produce using the given multiphonic fingering in the second multiphonic. In general, most of the multiphonics produced using this strategy can be achieved with only voicing adjustments, helped by a slight decrease in air pressure. Although embouchure force was not measured in the current study, the author noticed that a perceptible adjustment in embouchure force is often unnecessary for producing these multiphonics; in fact, the upper pitch intonation of some multiphonics can be improved by slightly *increasing* embouchure force. Since the adjustments made for multiphonics produced using **Strategy B** is very minute, ultrasound images were analyzed using ImageJ to help identify tongue motion. The distance between P (2.52, 3.95), defined by the posterior edge of the imaging sector, and the coordinate where the tongue contour intersects the $x=2.52$ axis is measured (as seen in figure 14) on ultrasound images of the tongue while producing the upper note and multiphonic. The coordinate where the tongue contour intersects the $x=2.52$ axis is 1.80mm higher in the image captured while playing the multiphonic. Measurements are calculated based on the conversion from pixels to inches performed by ImageJ based on the scan depth of the image and then converted to millimeters manually using the conversion scale of 1 inch equals 25.4 millimeters.



Ultrasound images of the tongue while playing a multiphonic produced using Strategy B. The back of the tongue is slightly raised, and the tongue contour is more rounded.

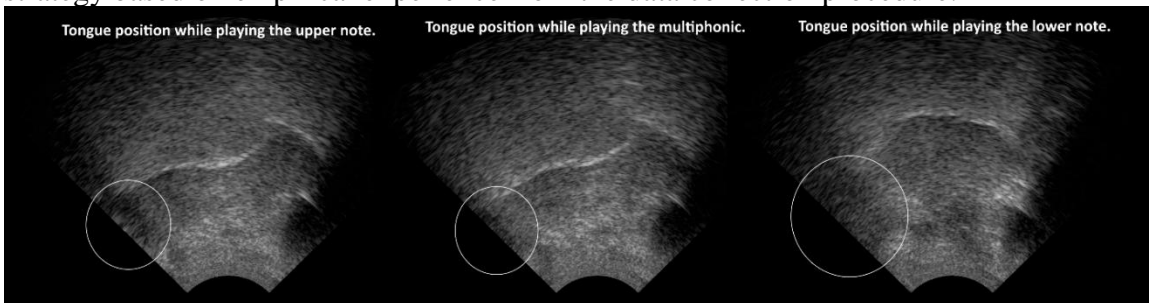
Multiphonics produced using **Strategy C** avoid notes from the chalumeau register. These include multiphonics that use a conventional clarion register fingering to produce the clarion note and a higher note. No consistent trends were noticed between different multiphonics produced using this strategy. The multiphonic tongue position appears to be an intermediate position—usually more similar to the voicing of the upper note—of the voicings to produce each pitch individually. To produce these multiphonics, start by playing both notes individually and take note of the voicing for both notes. Then, starting on the upper note, slowly alter the voicing to that of the lower note until both pitches speak. The author noticed during the investigative process that that multiphonics produced using this strategy are more difficult to master, though the difficulty is in the ability to sustain and not over-adjust rather than in finding the correct voicing. In the initial attempts, the performer will likely be able to produce the multiphonic, though only for a few milliseconds, before the upper note disappears. The performer should continue to experiment with the amount of adjustment and slight variations in the adjustment until

the multiphonic can be sustained. Since no consistent trends were noticed in the voicing manipulation of multiphonics produced using this strategy, it is difficult to offer generalized suggestions on how to adjust embouchure or air to produce these multiphonics. Fortunately, very few multiphonics are produced this way, and they can all be produced solely with perceptible changes in voicing.



Ultrasound images of the tongue while playing a multiphonic produced using Strategy C. The back of the tongue moves up and forward, forming a shape that has characteristics of the voicing for the lower note, where there is only one apex and the tongue position is higher and more rounded.

Multiphonics produced with **Strategy D** include an upper note between E-flat6 and G6 and a lower note between G4 and B-flat4. These multiphonics require a manipulation similar to multiphonics in **Strategy B**. Start by playing the upper note of the multiphonic, but instead of raising the back portion of the tongue, the tongue root—which is obscured by the hyoid bone—is raised, while no motion can be observed in the remainder of the tongue. Since the hyoid bone obscures the tongue root, an ultrasound image of the motion required to produce these multiphonics cannot be captured. However, the motion can be observed externally. While making this adjustment, the muscular and skeletal structures in the upper throat region can be seen moving upwards. It is important to note that the sensation felt when making this adjustment is mostly perceived in the throat region. As such, when attempting to make this adjustment, thinking about “constricting, tightening, or closing the throat,” and making adjustments to the throat can yield better success rate than attempting to actively manipulate the tongue. It is important to note that a few multiphonics produced using **Strategy D** can also be produced using **Strategy A** or **B**, while some multiphonics produced using **Strategy A** or **B** can be produced using **Strategy D**. The assigned strategy is the more effective and consistent strategy based on empirical experience from the data collection procedure.



Ultrasound images of the tongue while playing a multiphonic produced using Strategy D. The images for the tongue position playing the upper note and the

tongue position playing the multiphonic are relatively unchanged when overlaid. However, the hyoid bone shadow is moved further back. Since the transducer is fixed with the ultrasound probe headset, this suggests a change in the muscular and skeletal structures as mentioned.

Multiphonics for Test Subjects

The letter labelled below each multiphonic corresponds to the method of production as described in the written material.

Images of the tongue position while playing the upper note, lower note, and multiphonic using the multiphonic fingering will be captured.

The image displays two rows of musical notation for multiphonics, each with a corresponding tongue position diagram above it. The diagrams show a vertical line of dots representing the tongue's position, with some dots filled (black) and some open (white). The musical notation is on a single staff with a treble clef and a key signature of one flat (B-flat).

Row 1:

- Multiphonic A:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a double bar line below it.
- Multiphonic A:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a sharp sign above it and a double bar line below it.
- Multiphonic A:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a flat sign above it and a double bar line below it.
- Multiphonic B:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a flat sign above it and a double bar line below it.
- Multiphonic B:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a sharp sign above it and a double bar line below it.

Row 2:

- Multiphonic B:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a flat sign above it and a double bar line below it.
- Multiphonic C:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a sharp sign above it and a double bar line below it.
- Multiphonic C:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a flat sign above it and a double bar line below it.
- Multiphonic D:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a sharp sign above it and a double bar line below it.
- Multiphonic D:** The diagram shows a vertical line of dots with the top dot filled and the bottom dot open. The musical notation shows a B-flat note with a sharp sign above it and a double bar line below it.

APPENDIX D

ULTRASOUND IMAGES OF SUBJECT A

Equipment used by subject A:
Clarinet: LeBlanc Legacy
Barrel: Backun MoBa 66mm
Mouthpiece: Vandoren BD5 Series 13
Ligature: Vandoren Optimum
Reed: V12 3.5

Previous experience with multiphonics:
Subject has played a few compositions that use multiphonics.

Subject attempted to learn the multiphonics using the provided instruction, however, subject ultimately deviated from the provided instructions and relied on previous experience. However, the subject felt that with more time allocated for learning the multiphonics, the instruction provided may have been more helpful.

Depth of ultrasound images collected for this subject: 9cm

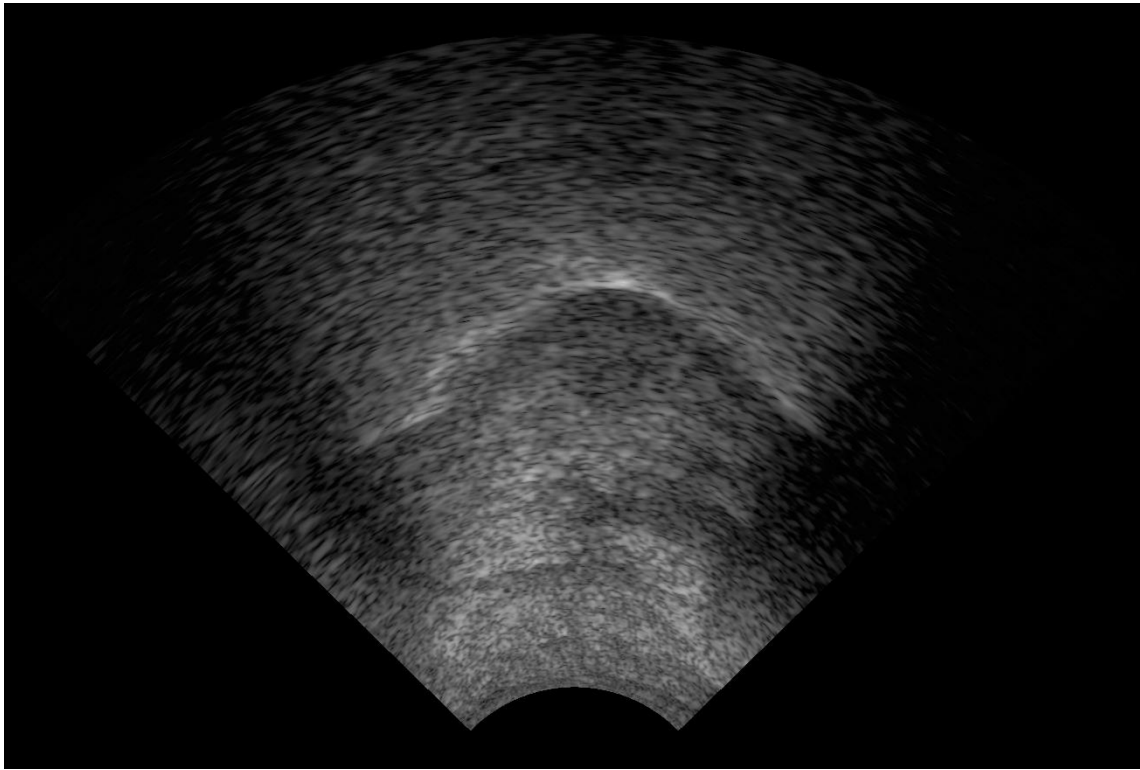


Figure 19. Ultrasound image of Subject A's tongue at rest.

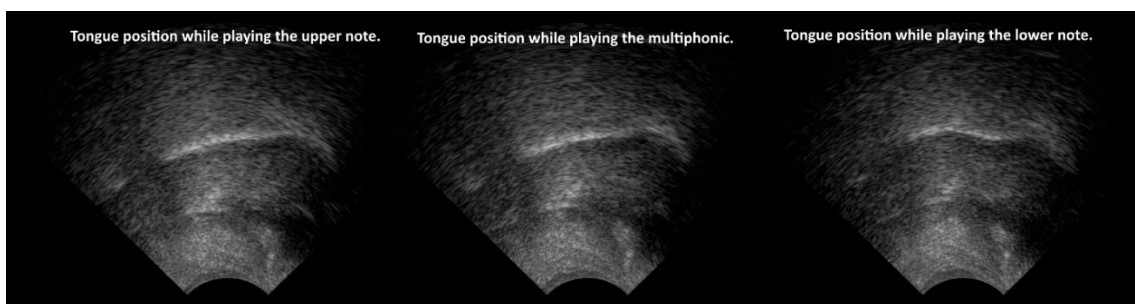


Figure 20. Ultrasound images of Subject A playing multiphonic 1. Subject was unable to sustain the multiphonic.

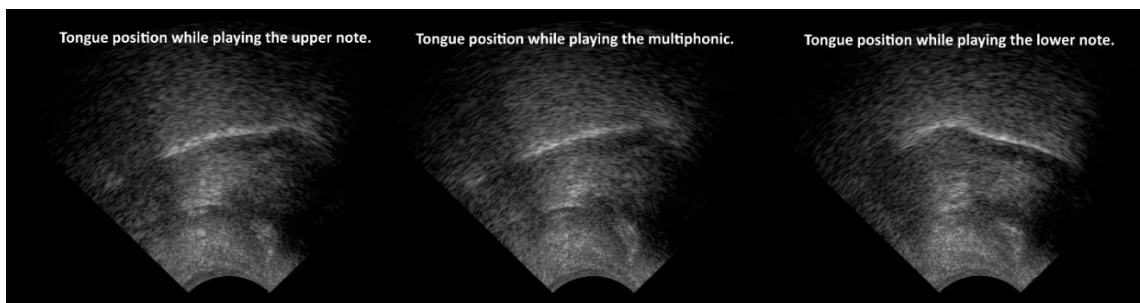


Figure 21. Ultrasound images of Subject A playing multiphonic 2. Subject was unable to sustain upper note. The upper note of the multiphonic produced was one partial too high and the multiphonic was difficult to sustain.

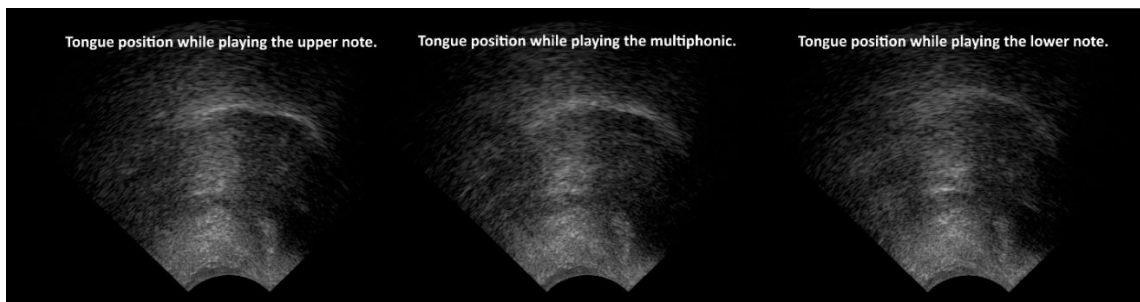


Figure 22. Ultrasound images of Subject A playing multiphonic 3. Subject was unable to sustain upper note. The multiphonic was difficult to sustain.

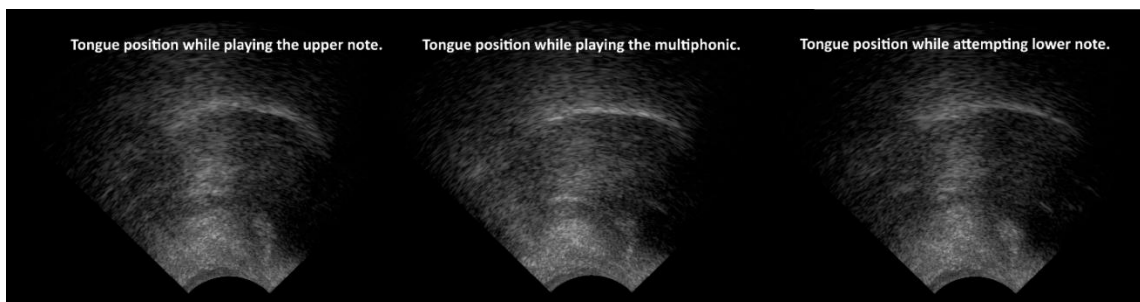


Figure 23. Ultrasound images of Subject A playing multiphonic 4. Subject was unable to play the lower note by itself.

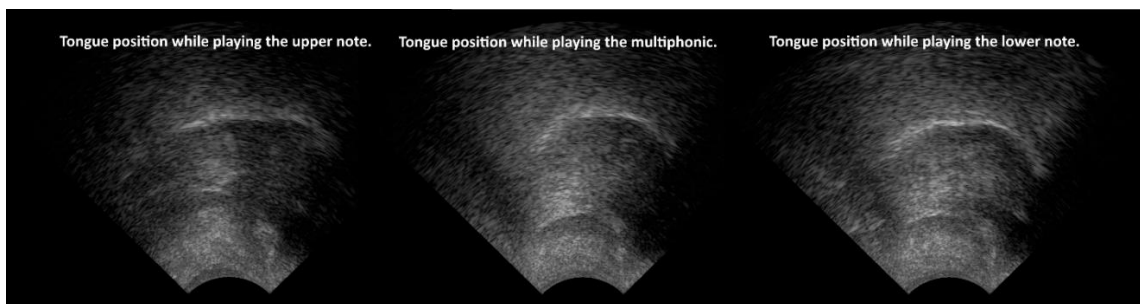


Figure 24. Ultrasound images of Subject A playing multiphonic 5. Subject had difficulty playing lower note by itself.

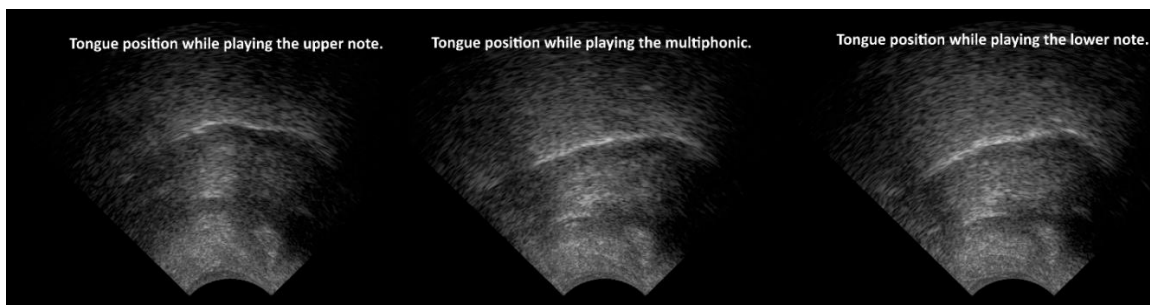


Figure 25. Ultrasound images of Subject A playing multiphonic 6.

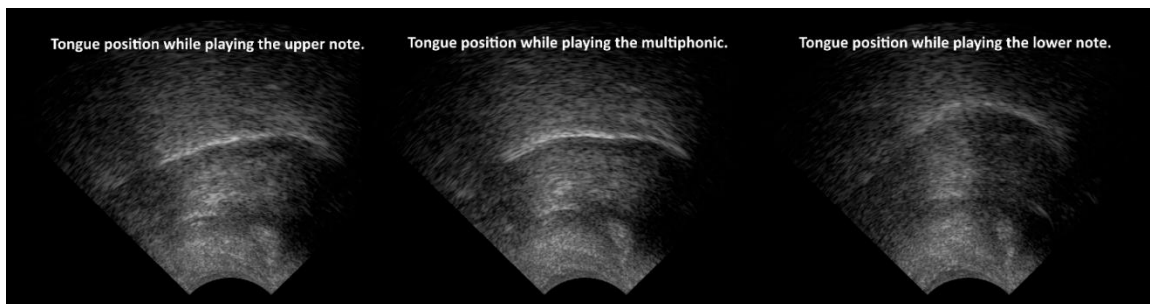


Figure 26. Ultrasound images of Subject A playing multiphonic 7. Subject had difficulty sustaining the multiphonic.

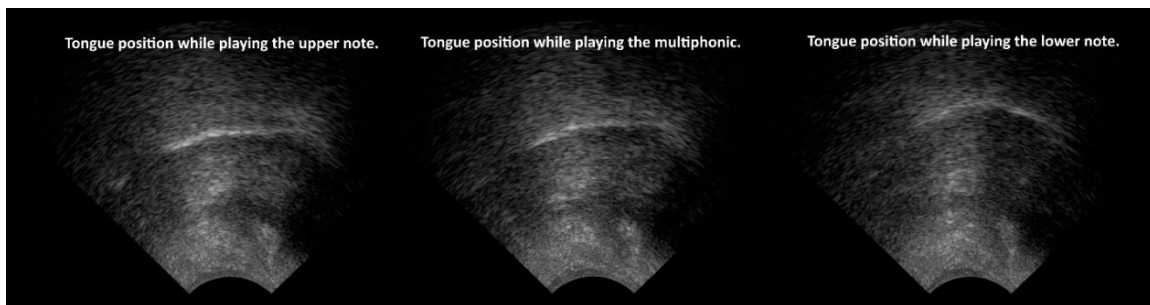


Figure 27. Ultrasound images of Subject A playing multiphonic 8. Subject had difficulty sustaining the multiphonic.

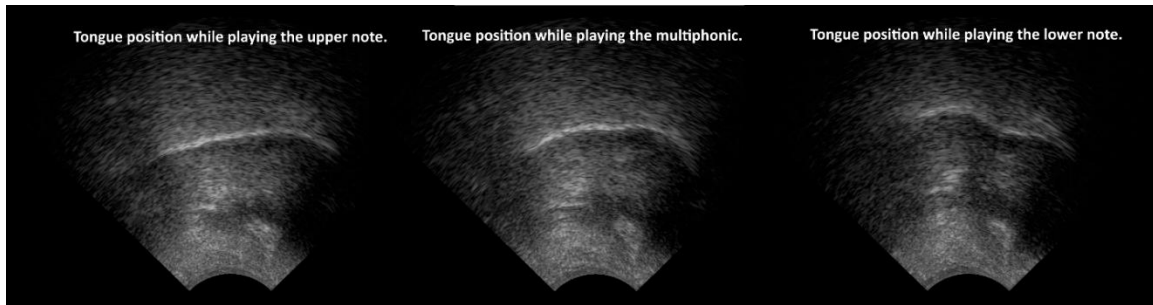


Figure 28. Ultrasound images of Subject A playing multiphonic 9.

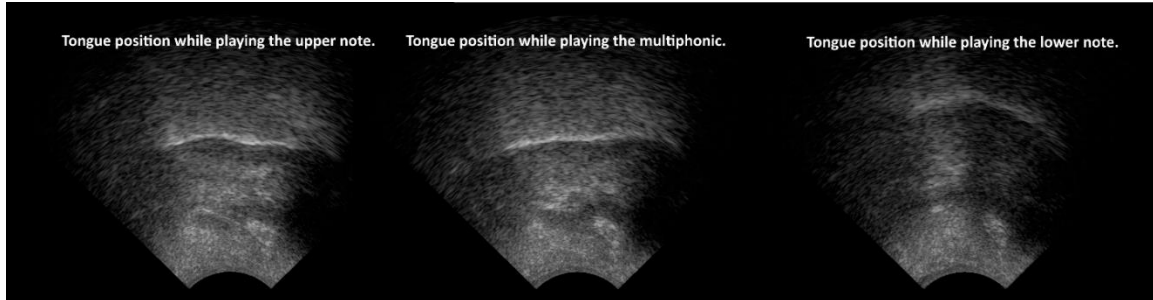


Figure 29. Ultrasound images of Subject A playing multiphonic 10.

APPENDIX E

ULTRASOUND IMAGES OF SUBJECT B

Equipment used by subject B:
Clarinet: Buffet R13
Barrel: Stock barrel 66mm
Mouthpiece: Vandoren BD5 Series 13
Ligature: Ishimori, gold plated
Reed: V12 3.5

Previous experience with multiphonics:
Subject has played a few compositions that use multiphonics before.

Subject used the instructions provided and found them helpful in learning to produce the given multiphonics.

Depth of ultrasound images collected for this subject: 9cm

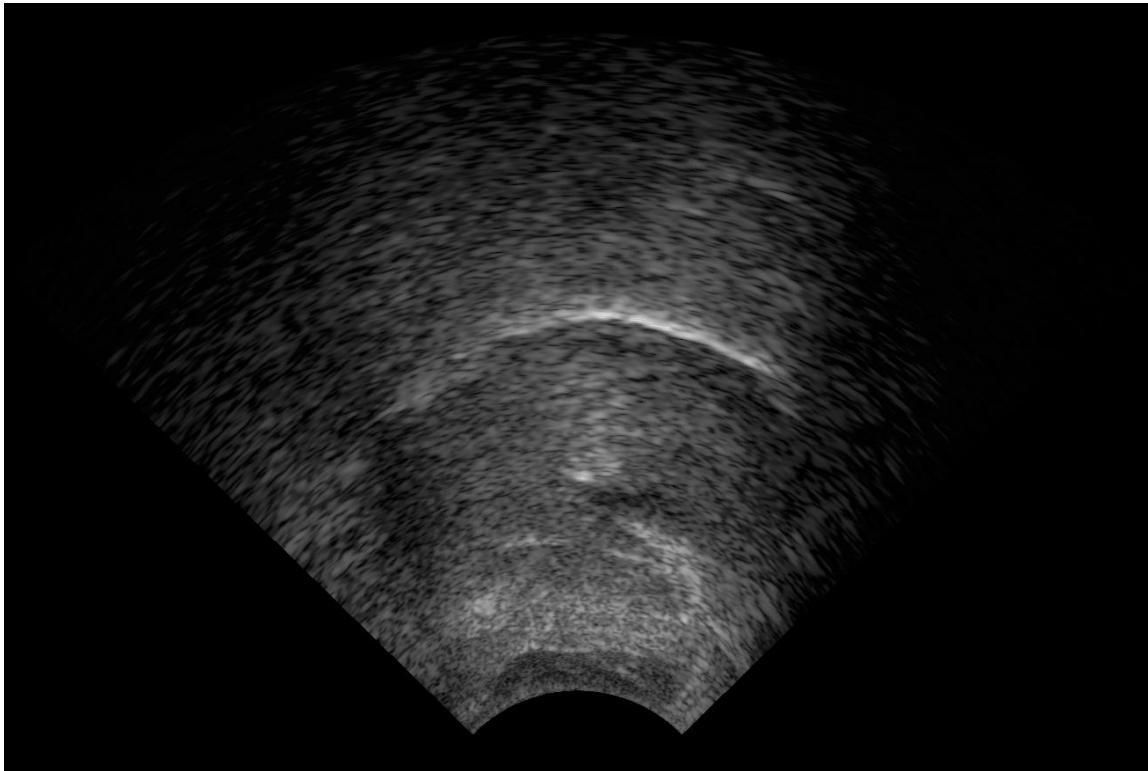


Figure 30. Ultrasound image of Subject B's tongue at rest.

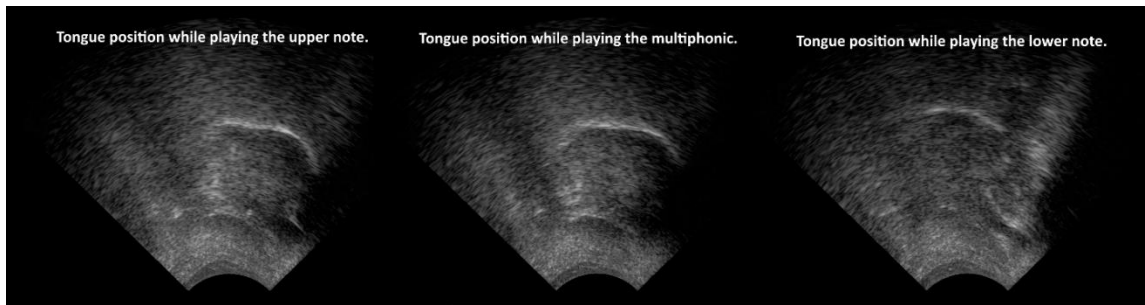


Figure 31. Ultrasound images of Subject B playing multiphonic 1. Subject had difficulty sustaining the multiphonic.

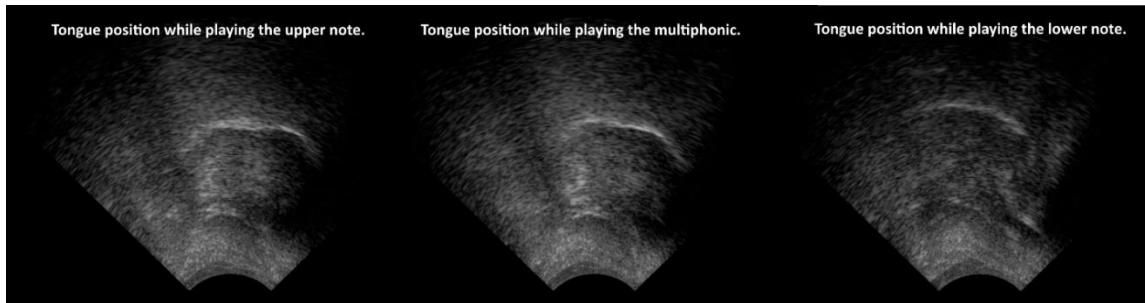


Figure 32. Ultrasound images of Subject B playing multiphonic 2.

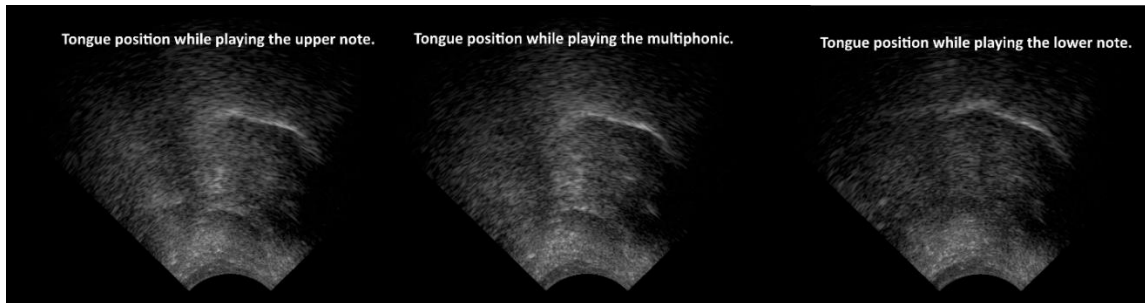


Figure 33. Ultrasound images of Subject B playing multiphonic 3. Subject had difficulty sustaining the multiphonic.

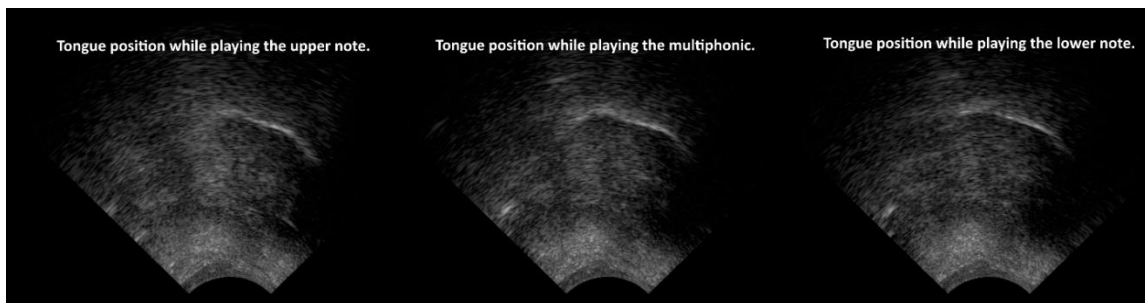


Figure 34. Ultrasound images of Subject B playing multiphonic 4. Subject had difficulty playing the lower note by itself.

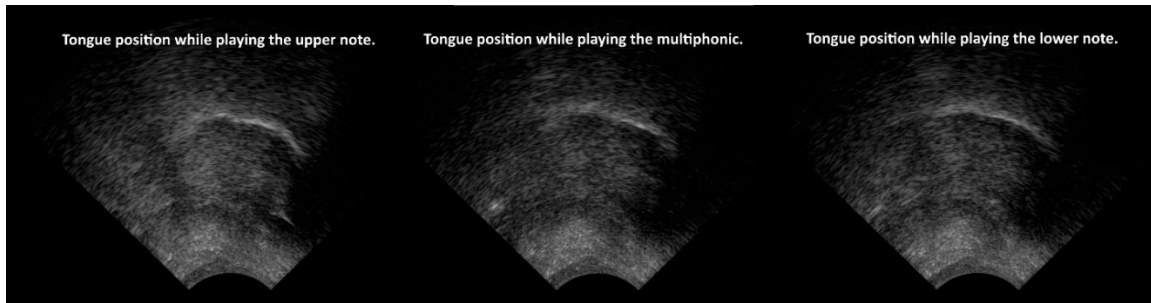


Figure 35. Ultrasound images of Subject B playing multiphonic 5. Subject had difficulty playing the lower note by itself.

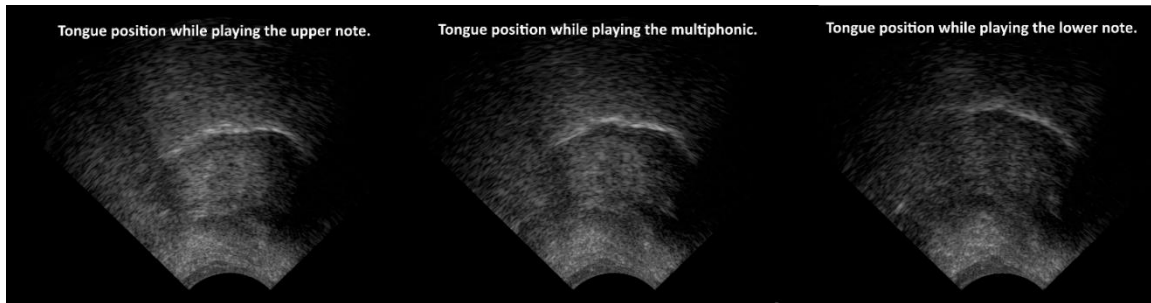


Figure 36. Ultrasound images of Subject B playing multiphonic 6.

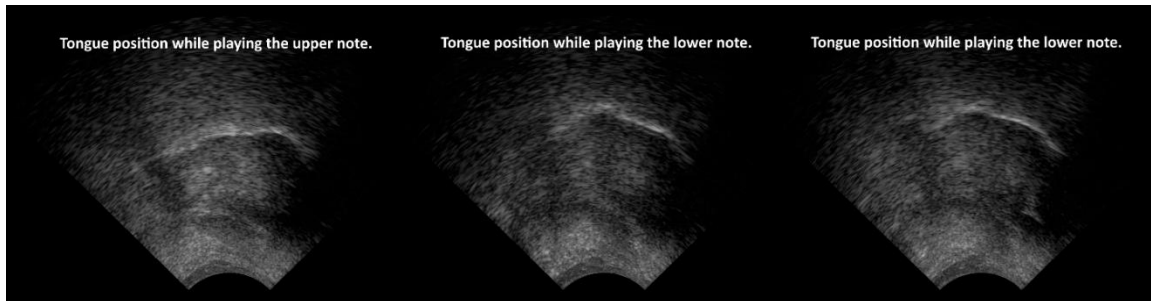


Figure 37. Ultrasound images of Subject B playing multiphonic 7. Subject had difficulty sustaining the multiphonic.

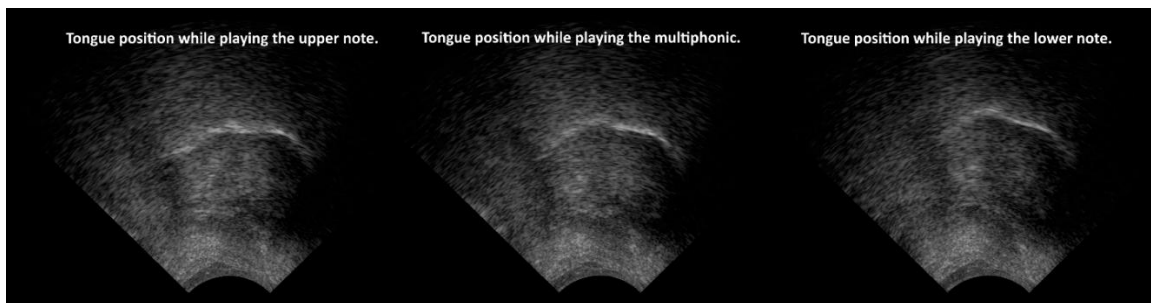


Figure 38. Ultrasound images of Subject B playing multiphonic 8. Subject had difficulty sustaining the multiphonic.

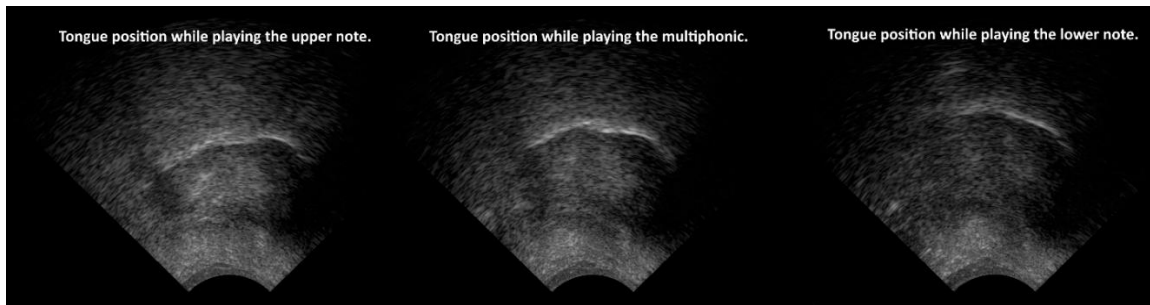


Figure 39. Ultrasound images of Subject B playing multiphonic 9.

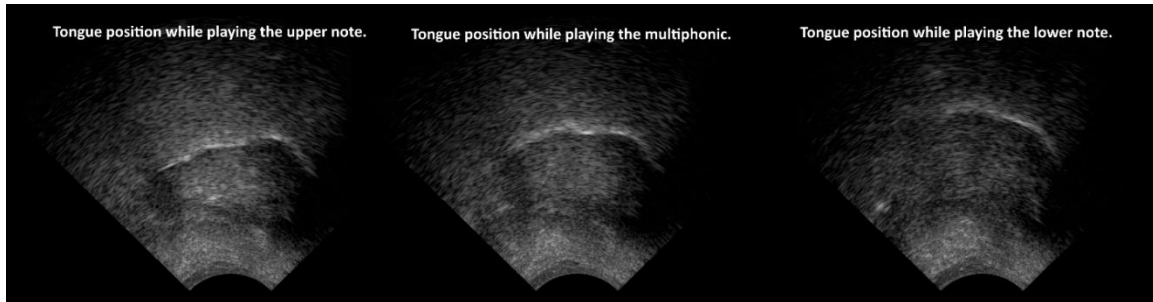


Figure 40. Ultrasound images of Subject B playing multiphonic 10.

APPENDIX F

ULTRASOUND IMAGES OF SUBJECT C

Equipment used by subject C:
Clarinet: Buffet R13
Barrel: Stock barrel 66mm
Mouthpiece: Vandoren B40 Series 13
Ligature: Ishimori, rose gold plated
Reeds: V12 3.5

Previous experience with multiphonics:
Subject has played a few compositions and voicing exercises involving multiphonics.

Subject did not use the provided instructions and learned to produce the multiphonics based on past experience.

Depth of ultrasound images collected for this subject: 9cm

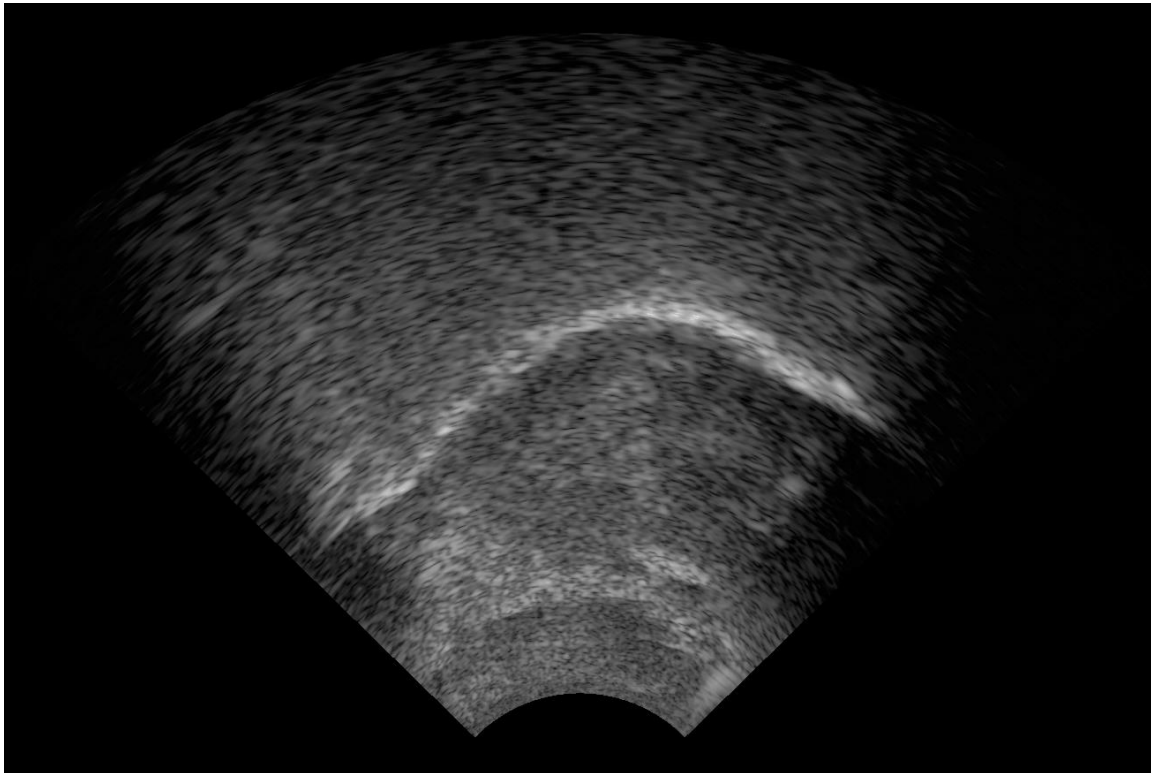


Figure 41. Ultrasound image of Subject C's tongue at rest.

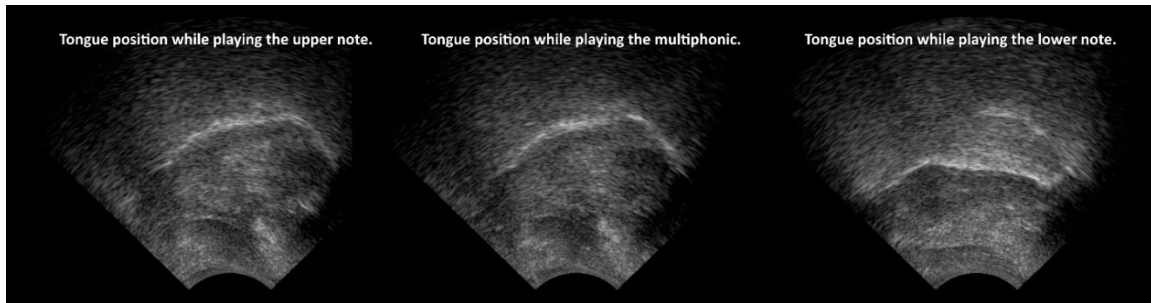


Figure 42. Ultrasound images of Subject C playing multiphonic 1. Subject was unable play the upper note by itself.

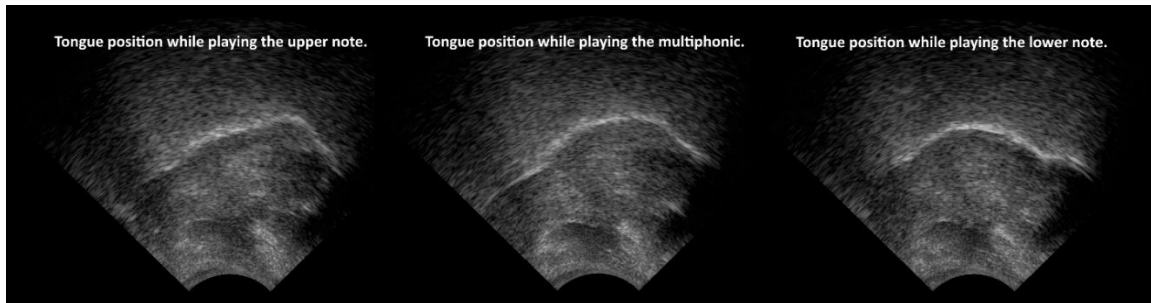


Figure 43. Ultrasound images of Subject C playing multiphonic 2. Subject had difficulty sustaining the upper note by itself.

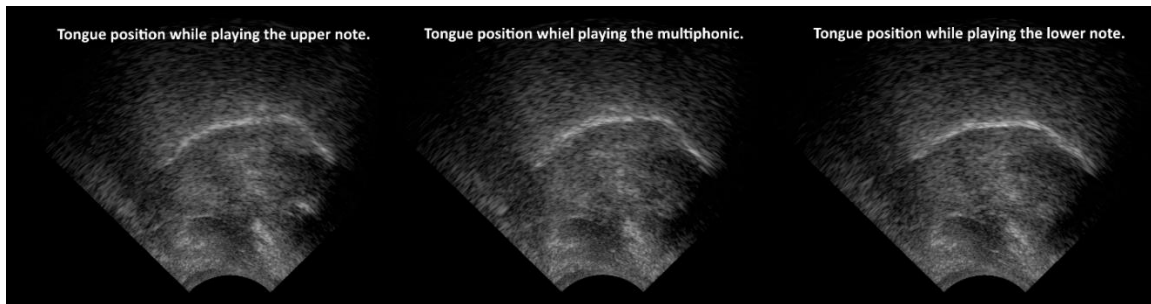


Figure 44. Ultrasound images of Subject C playing multiphonic 3. Subject had difficulty playing both the upper note by itself as well as difficulty playing the multiphonic.

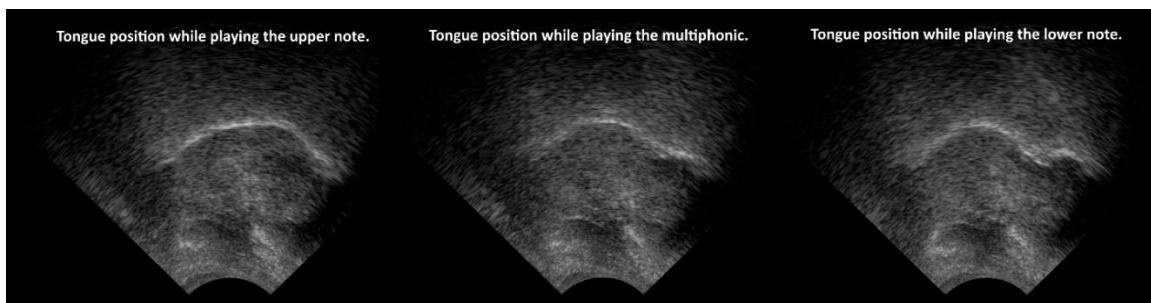


Figure 45. Ultrasound images of Subject C playing multiphonic 4. Subject had difficulty playing lower note by itself, when successful, the note is very quiet.

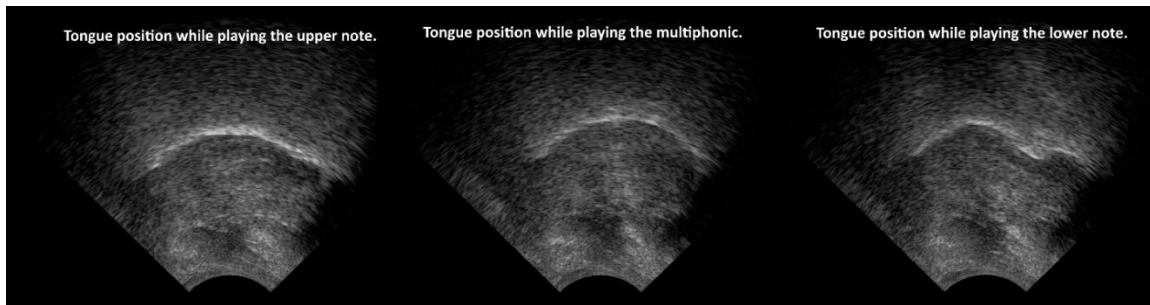


Figure 46. Ultrasound images of Subject C playing multiphonic 5.

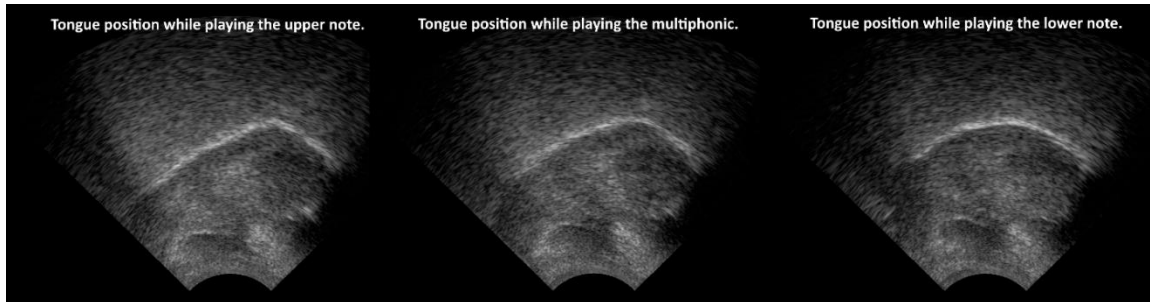


Figure 47. Ultrasound images of Subject C playing multiphonic 6.



Figure 48. Ultrasound images of Subject C playing multiphonic 7. Subject had difficulty playing the multiphonic.

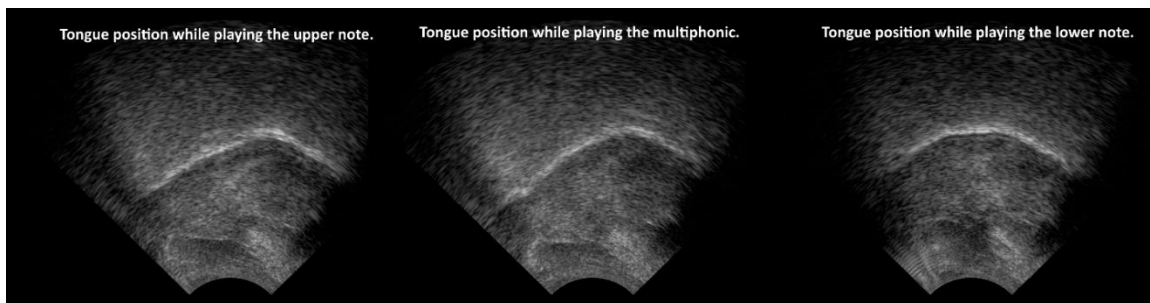


Figure 49. Ultrasound images of Subject C playing multiphonic 8.

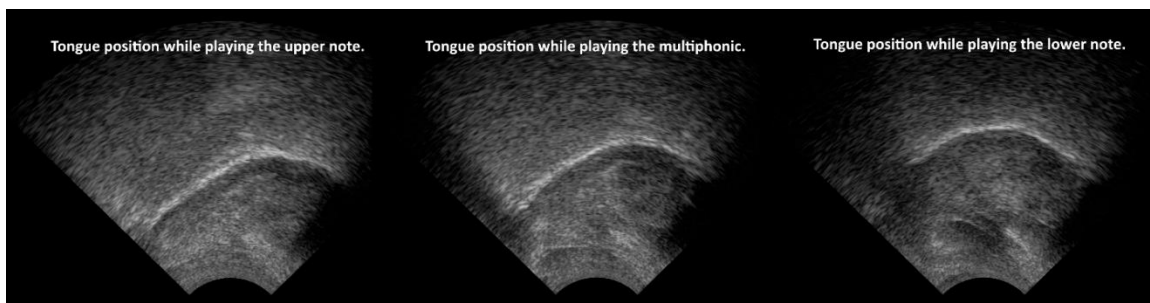


Figure 50. Ultrasound images of Subject C playing multiphonic 9.

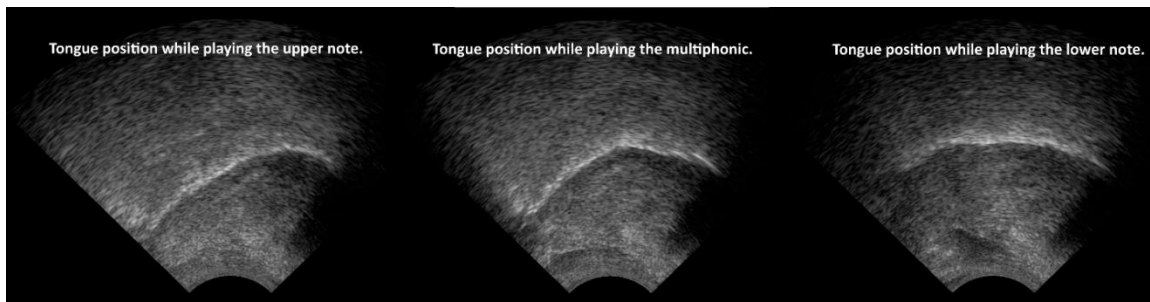


Figure 51. Ultrasound images of Subject C playing multiphonic 10.

APPENDIX G

ULTRASOUND IMAGES OF SUBJECT D

Equipment used by subject D:
Clarinet: Buffet R13
Barrel: Buffet Icon Barrel 65mm
Mouthpiece: Roger Garrett DL
Ligature: Vandoren Optimum
Reeds: V12 3.5+

Previous experience with multiphonics:
Subject has extensive experience with multiphonics.

Subject did not use the instructions provided in learning to produce the multiphonics.
However, subject mentions that the instructions are familiar and are similar to techniques the subject has employed in the past in learning multiphonics.

Depth of ultrasound images collected for this subject: 10cm

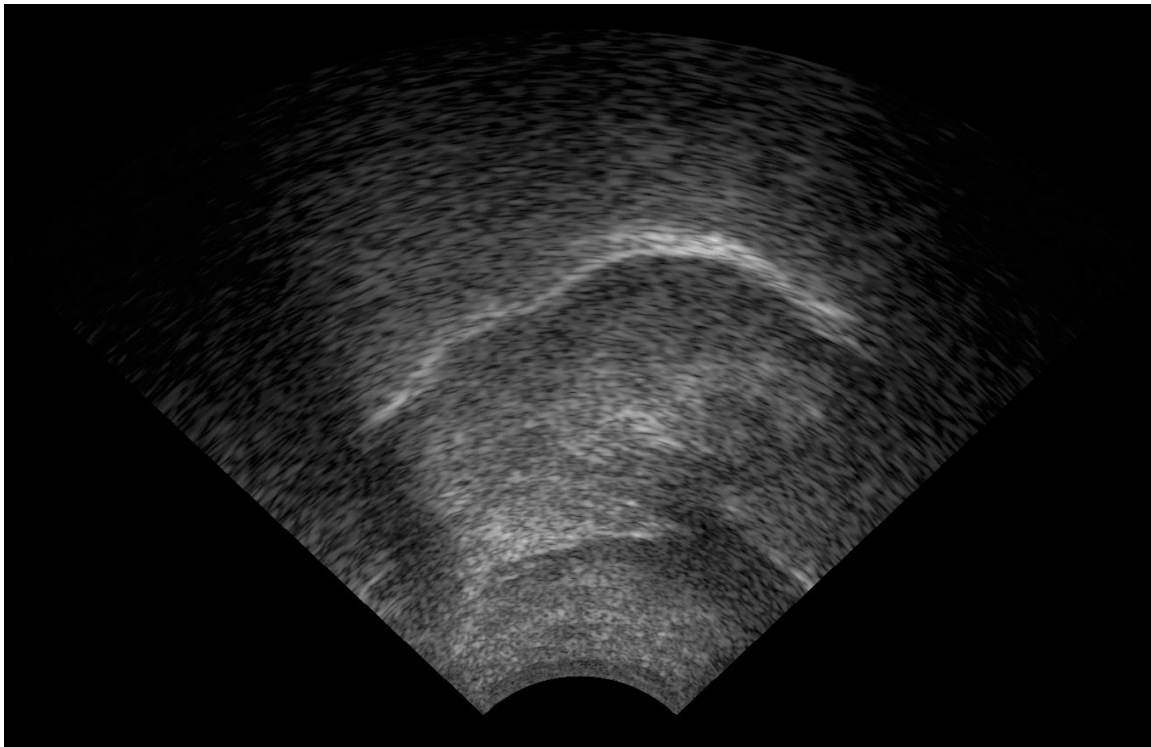


Figure 52. Ultrasound image of Subject D's tongue at rest.

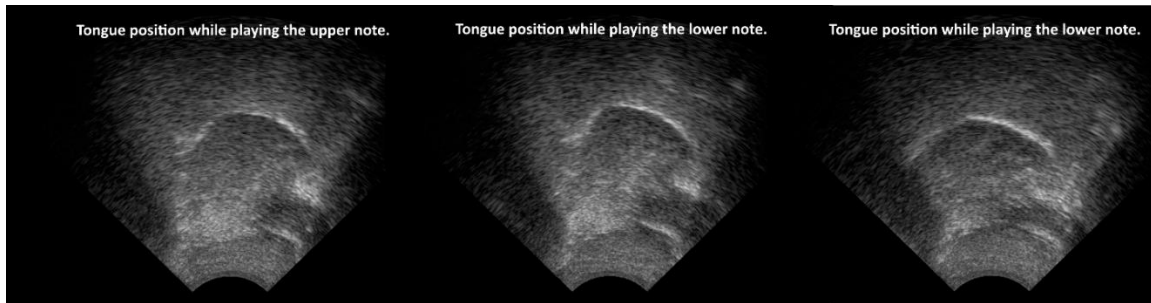


Figure 53. Ultrasound images of Subject D playing multiphonic 1. Subject had difficulty playing the upper note by itself.

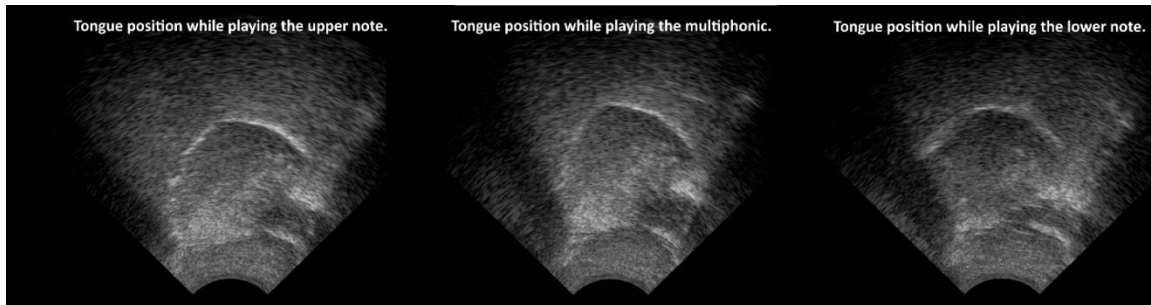


Figure 54. Ultrasound images of Subject D playing multiphonic 2.

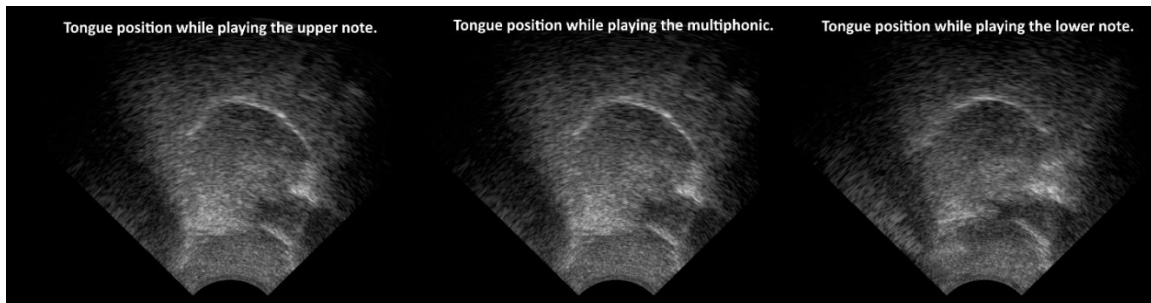


Figure 55. Ultrasound images of Subject D playing multiphonic 3. Subject had difficulty playing the upper note as by itself and the multiphonic was difficult to sustain.



Figure 56. Ultrasound images of Subject D playing multiphonic 4. Subject had difficulty playing the lower note by itself.

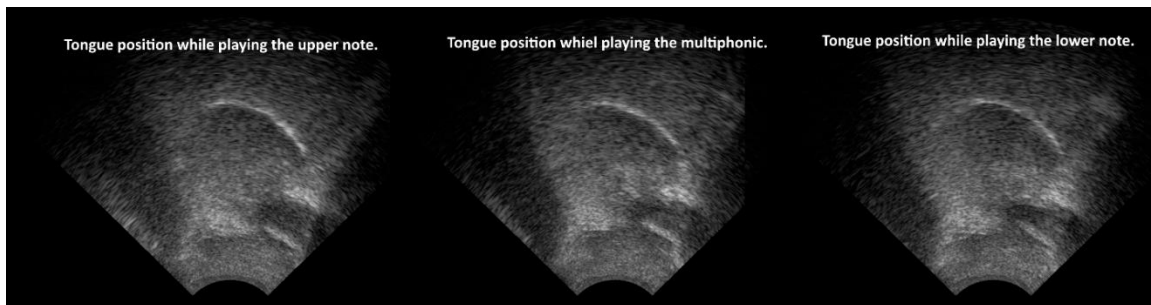


Figure 57. Ultrasound images of Subject D playing multiphonic 5. Subject had difficulty playing the lower note by itself.



Figure 58. Images of Subject D playing multiphonic 6. The upper note of the multiphonic is flat compared to when the subject played it by itself.



Figure 59. Images of Subject D playing multiphonic 7. Subject had difficulty producing and sustaining the multiphonic.

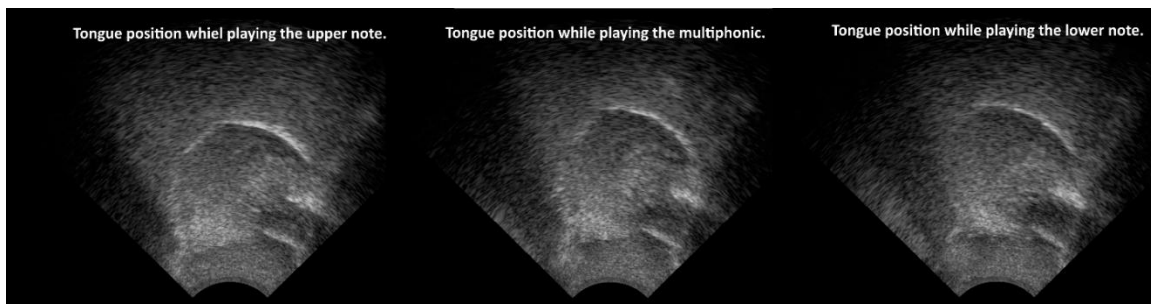


Figure 60. Images of Subject D playing multiphonic 8. Subject had difficulty producing the multiphonic.

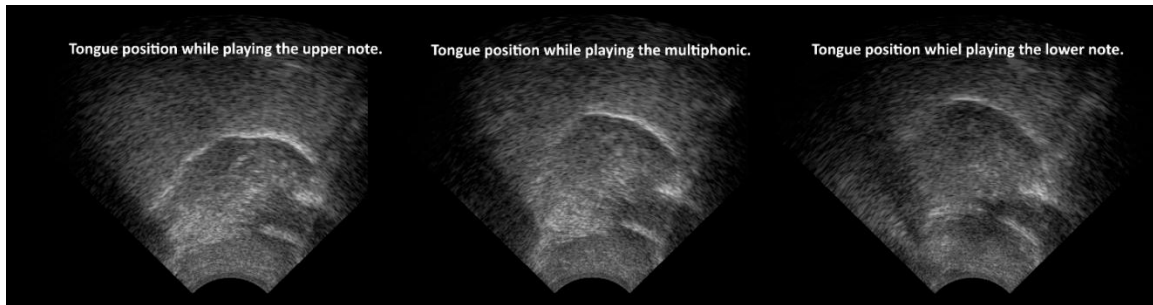


Figure 61. Images of Subject D playing multiphonic 9. The upper note of the multiphonic is flat compared to when the subject played it by itself.

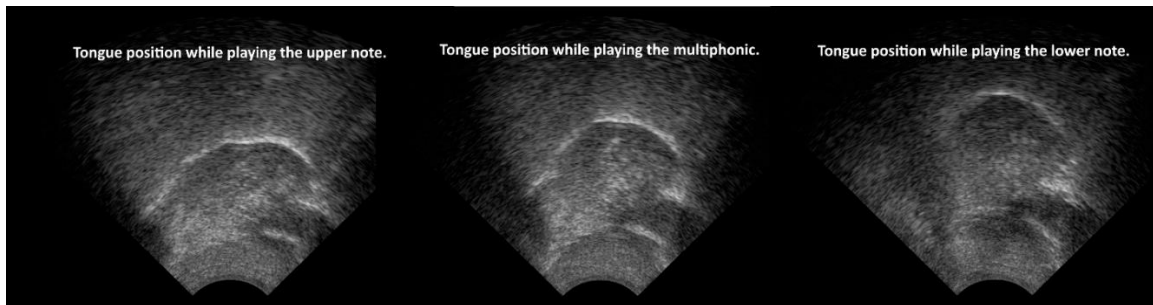


Figure 62. Images of Subject D playing multiphonic 10. Subject had difficulty sustaining the multiphonic.

Note: Subject D did not approach each multiphonic from the upper note as suggested in the text provided to the subject. This subject encounters multiphonic regularly in repertoire and has developed a personal strategy for approaching and learning multiphonics.

APPENDIX H

ULTRASOUND IMAGES OF SUBJECT E

Equipment used by subject E:
Clarinet: Buffet R13
Barrel: Buffet Icon 65mm
Mouthpiece: David McClune SP
Ligature: Bay Baroque, gold plated
Reeds: handmade

Previous experience with multiphonics:
Subject has played a few compositions that use multiphonics before.

Subject used a combination of the provided instructions and personal experimentation. However, the subject did not pay enough attention to the details of the instructions to determine whether the provided instructions were helpful.

Depth of ultrasound images collected for this subject: 8cm

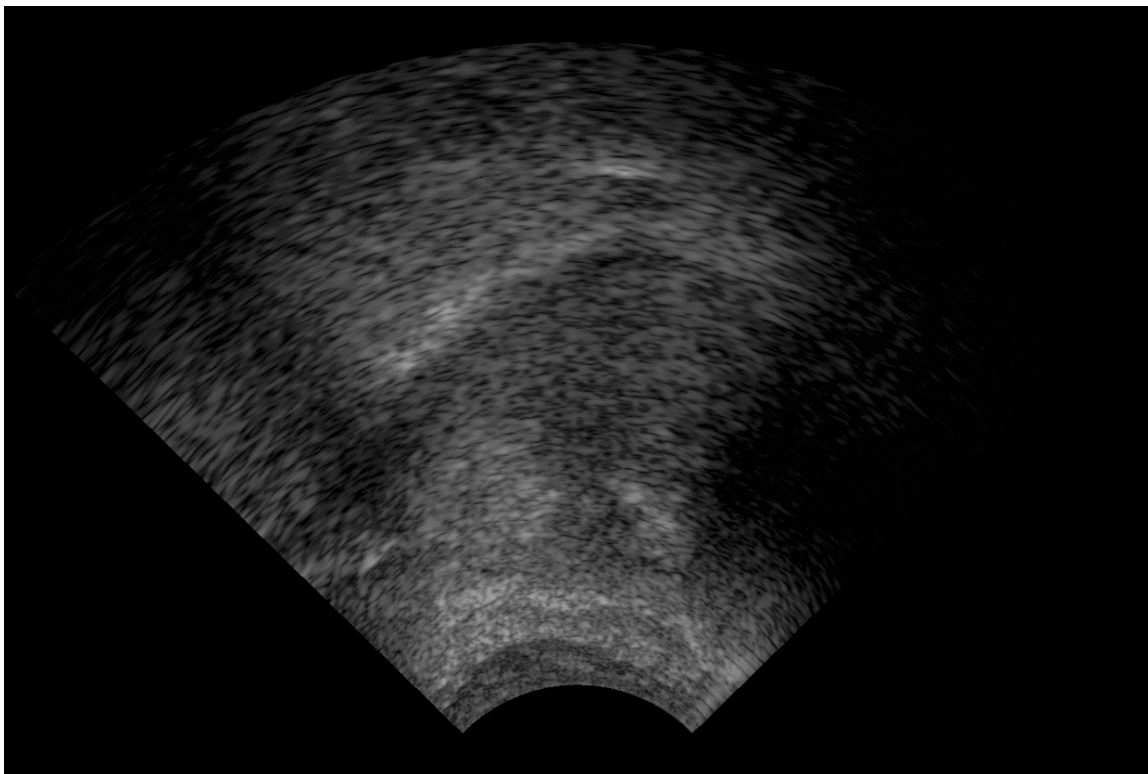


Figure 63. Ultrasound image of Subject E's tongue at rest.

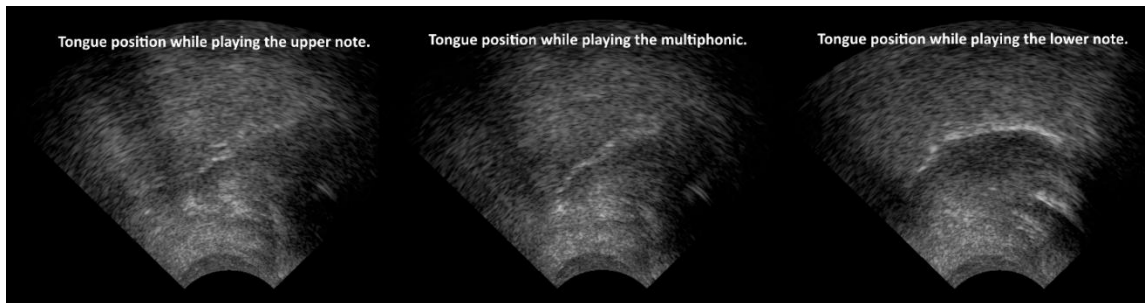


Figure 64. Ultrasound images of Subject E playing multiphonic 1. Subject had difficulty playing the upper note by itself. The upper note was also not as prominent as the lower note, notes of other partials surrounding the upper note can also be heard.

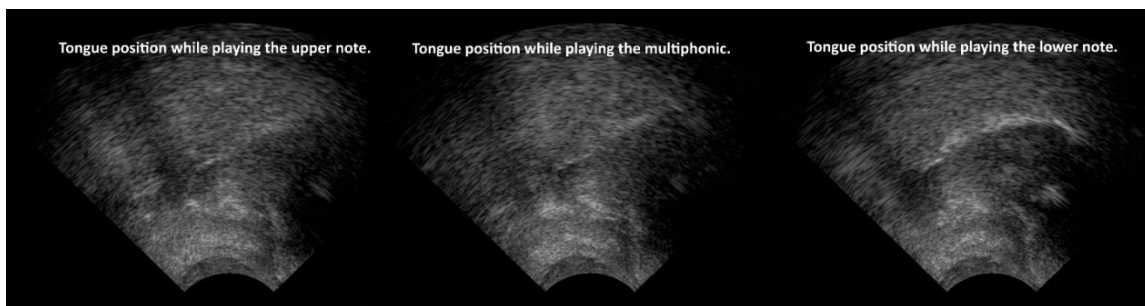


Figure 65. Ultrasound images of Subject E playing multiphonic 2.

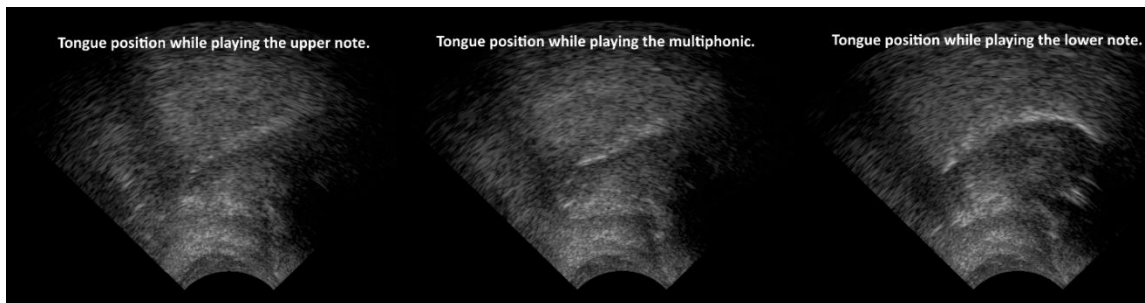


Figure 66. Ultrasound images of Subject E playing multiphonic 3. Subject had difficulty producing the multiphonic.

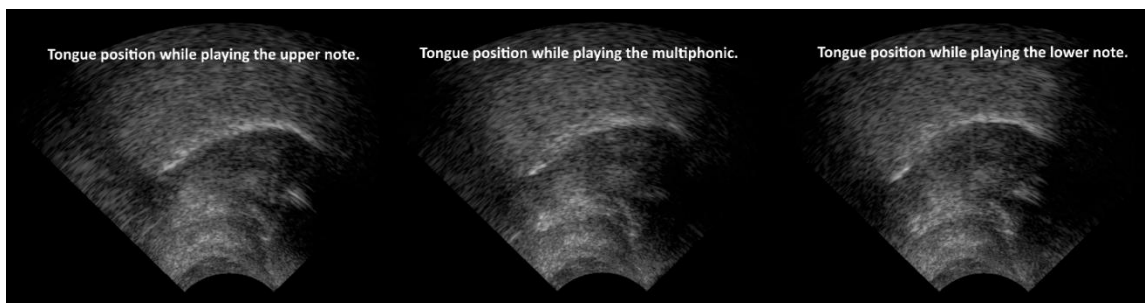


Figure 67. Ultrasound images of Subject E playing multiphonic 4.

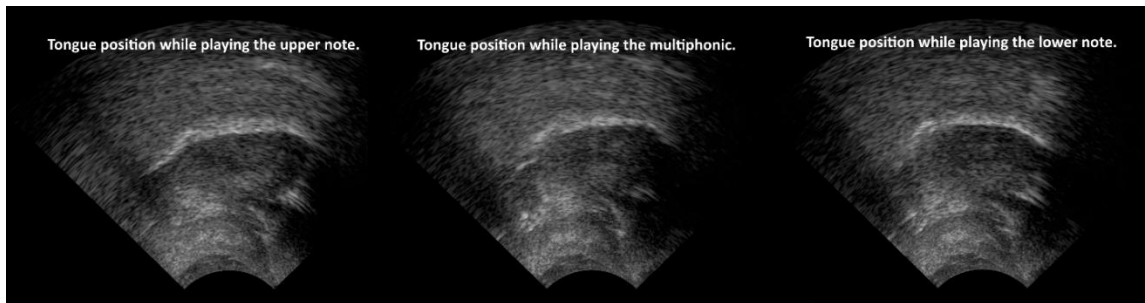


Figure 68. Ultrasound images of Subject E playing multiphonic 5. The upper note of the multiphonic is flat compared to when the subject played it by itself.

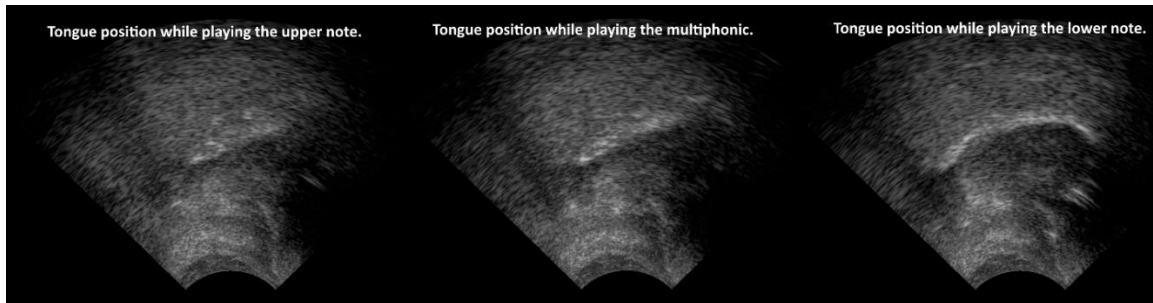


Figure 69. Ultrasound images of Subject E playing multiphonic 6.

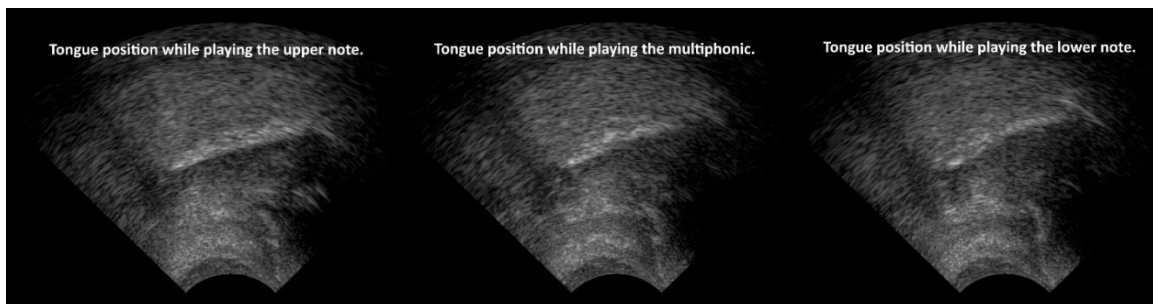


Figure 70. Ultrasound images of Subject E playing multiphonic 7. The upper note of the multiphonic is flat compared to when the subject played it by itself.

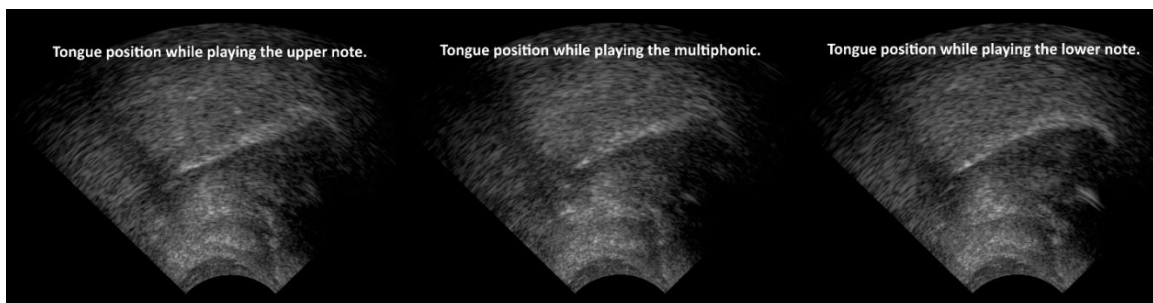


Figure 71. Ultrasound images of Subject E playing multiphonic 8. The upper note of the multiphonic is flat compared to when the subject played it by itself.

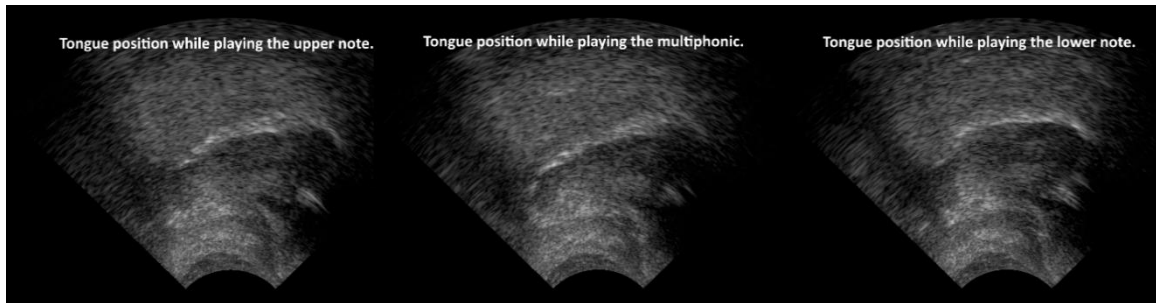


Figure 72. Ultrasound images of Subject E playing multiphonic 9. Subject had difficulty sustaining the multiphonic.

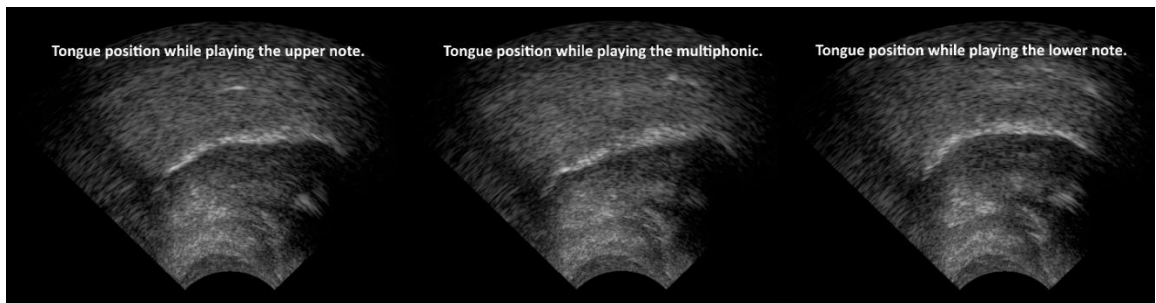


Figure 73. Ultrasound images of Subject E playing multiphonic 10.

APPENDIX I

ULTRASOUND IMAGES OF SUBJECT F

Equipment used by subject F:
Clarinet: Buffet R13 Greenline
Barrel: Stock barrel 66mm
Mouthpiece: Vandoren BD5 Series 13
Ligature: Vandoren M/O
Reeds: V12 3.5+

Previous experience with multiphonics:
Subject has played a few compositions that use multiphonics before.

Subject used the instructions provided and found them helpful in learning to produce the given multiphonics.

Depth of ultrasound images collected for this subject: 10cm

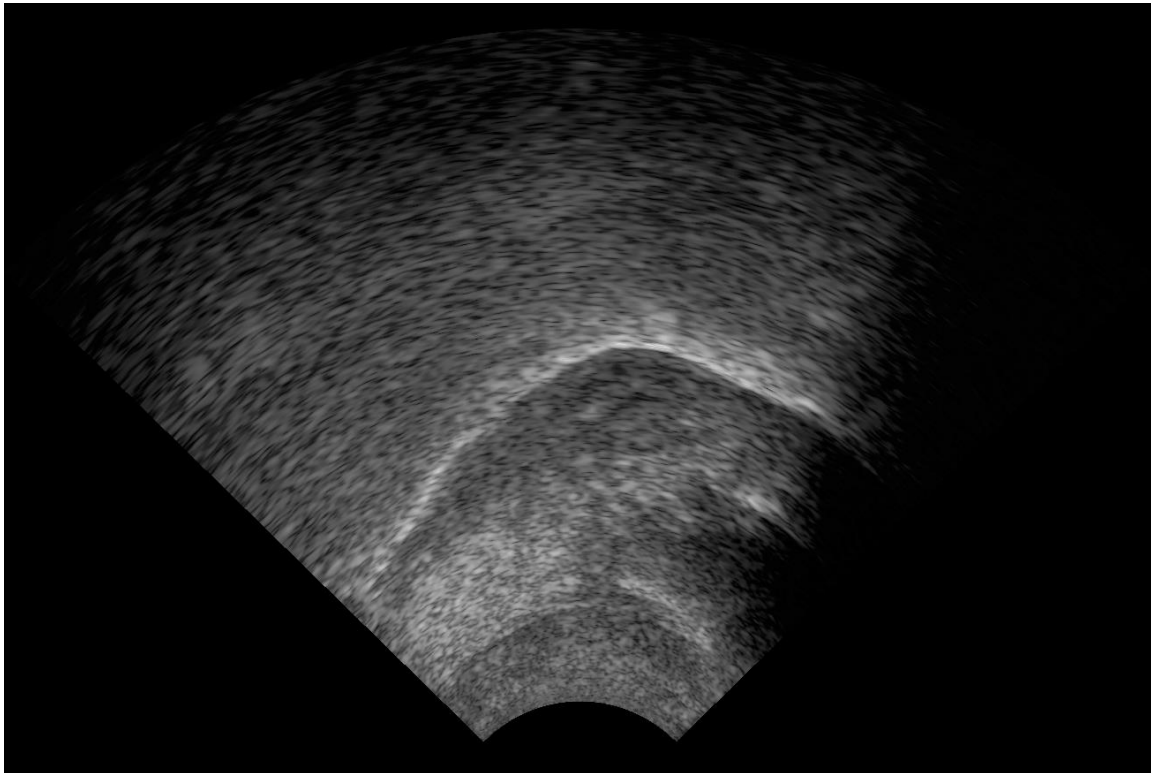


Figure 74. Ultrasound image of Subject F's tongue at rest.

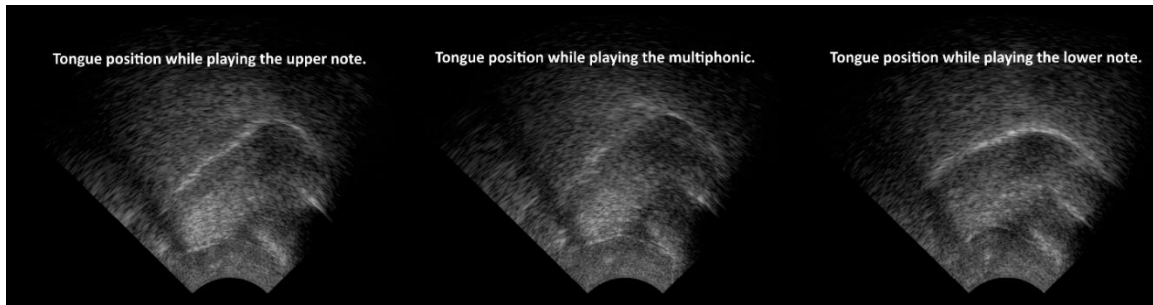


Figure 75. Ultrasound images of Subject F playing multiphonic 1.

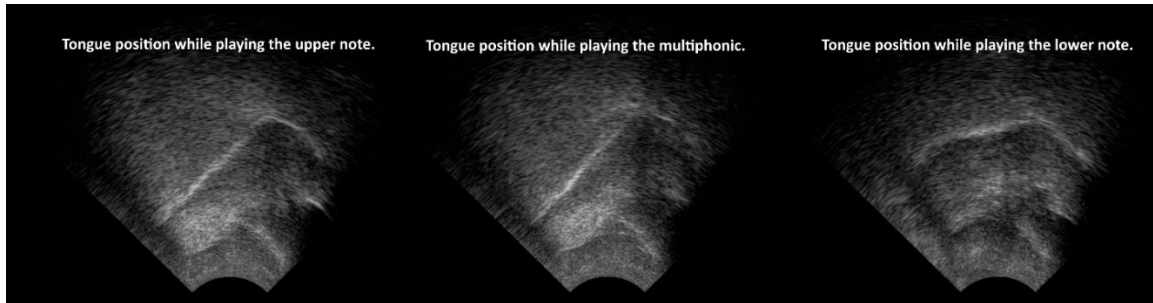


Figure 76. Ultrasound images of Subject F playing multiphonic 2.

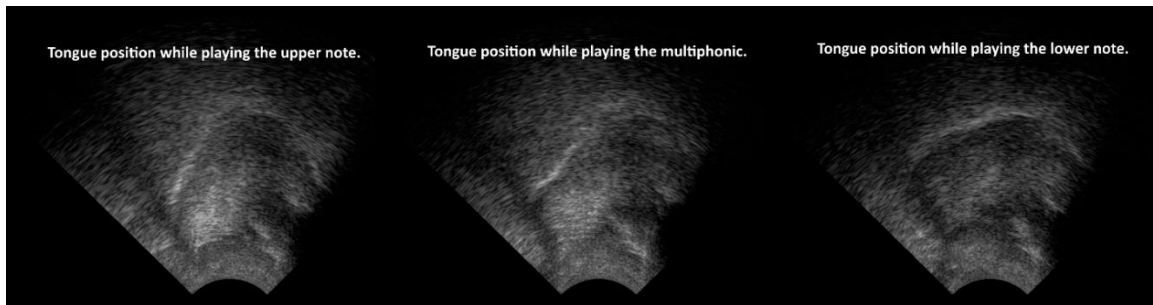


Figure 77. Ultrasound images of Subject F playing multiphonic 3.

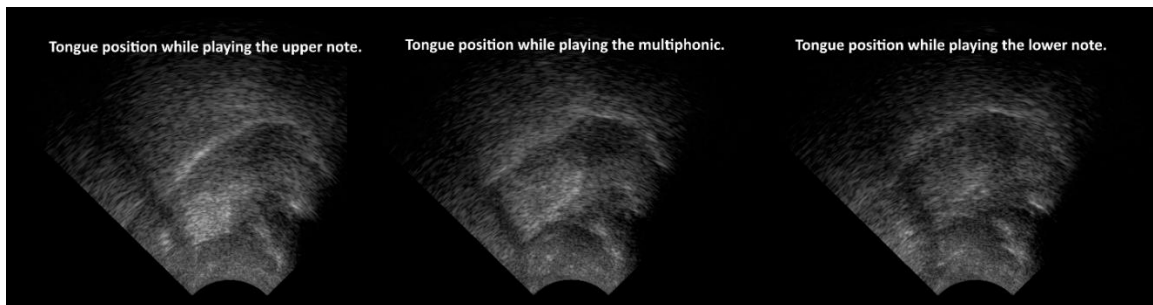


Figure 78. Ultrasound images of Subject F playing multiphonic 4.

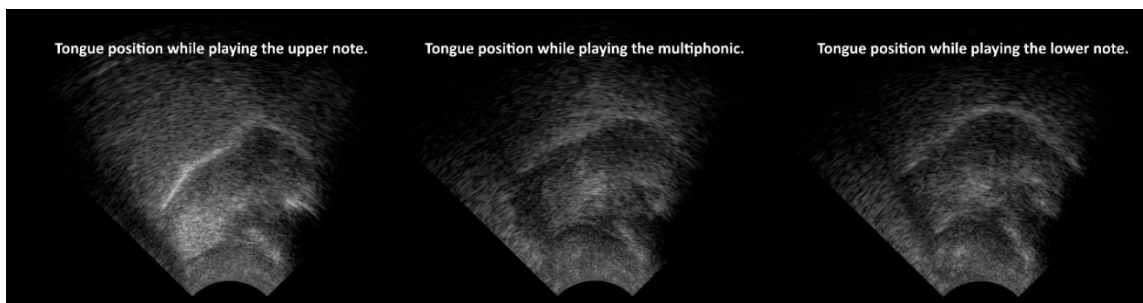


Figure 79. Ultrasound images of Subject F playing multiphonic 5.

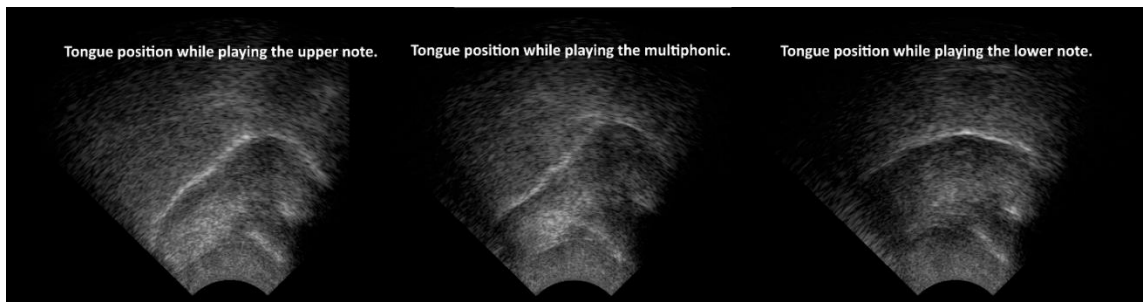


Figure 80. Ultrasound images of Subject F playing multiphonic 6.

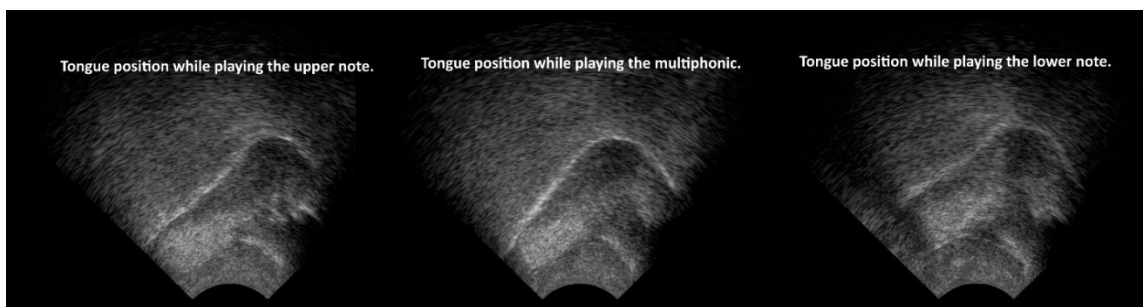


Figure 81. Ultrasound images of Subject F playing multiphonic 7.

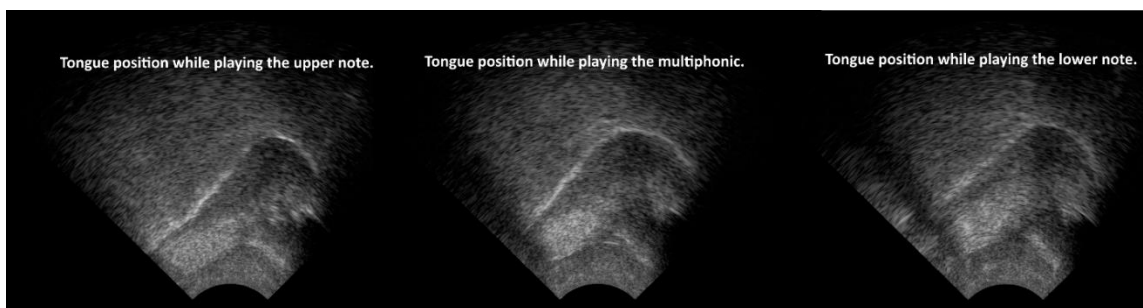


Figure 82. Ultrasound images of Subject F playing multiphonic 8.

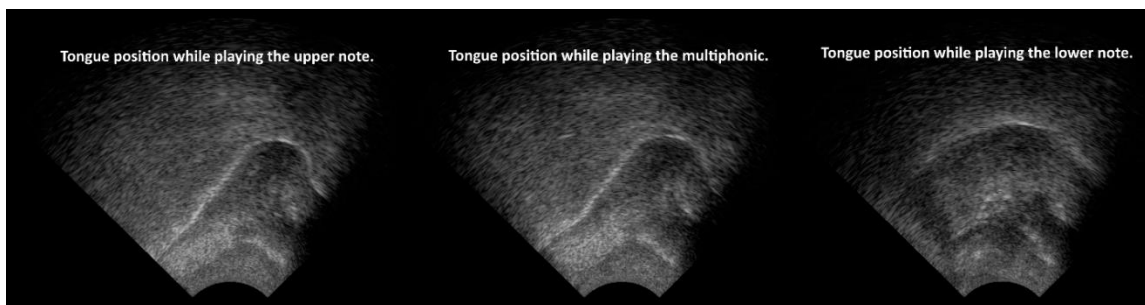


Figure 83. Ultrasound images of Subject F playing multiphonic 9.

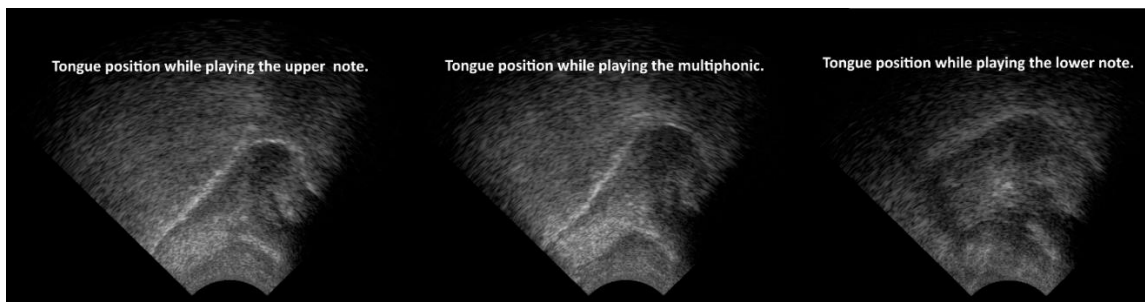


Figure 84. Ultrasound images of Subject F playing multiphonic 10.

APPENDIX J

ULTRASOUND IMAGES OF SUBJECT G

Equipment used by subject G:
Clarinet: Buffet R13 Greenline
Barrel: Robert Scott 66mm
Mouthpiece: David McClune SP
Ligature: Vandoren M/O
Reeds: V12 3.5

Previous experience with multiphonics:
Subject has played a few compositions that use multiphonics before.

Subject used the instructions provided and found them helpful in learning to produce the given multiphonics.

Depth of ultrasound images collected for this subject: 11cm

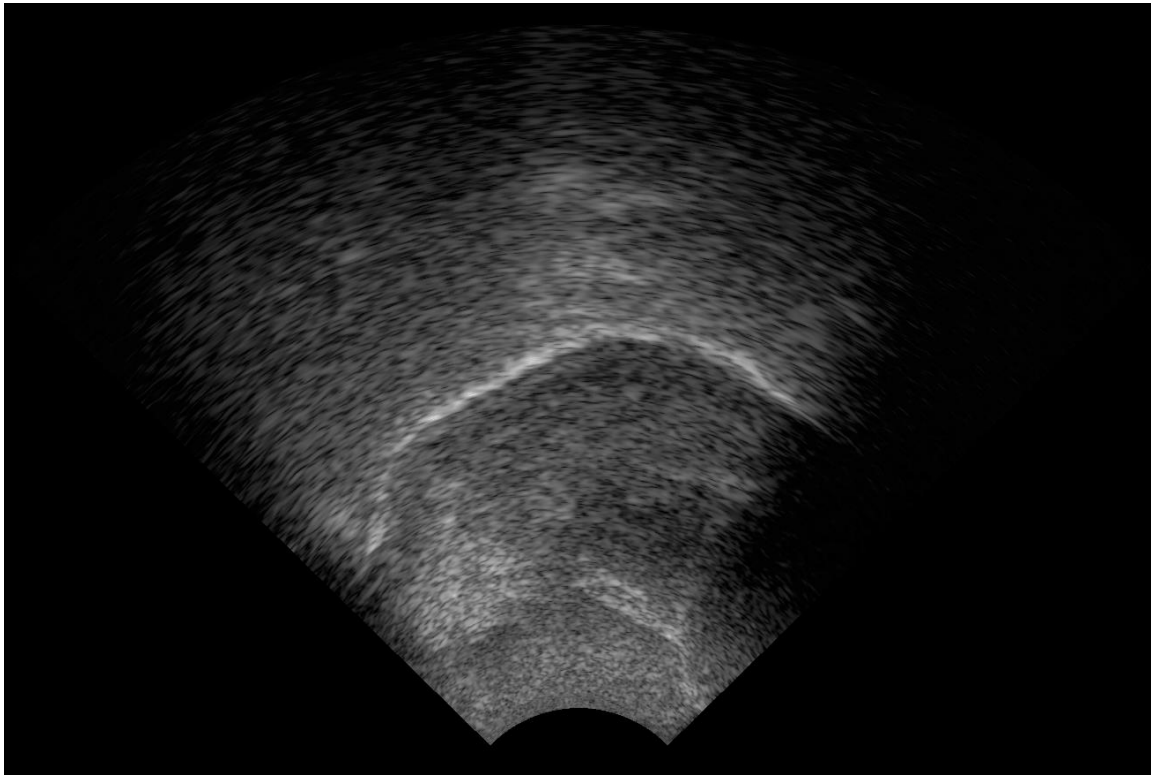


Figure 85. Ultrasound image of Subject G's tongue at rest.

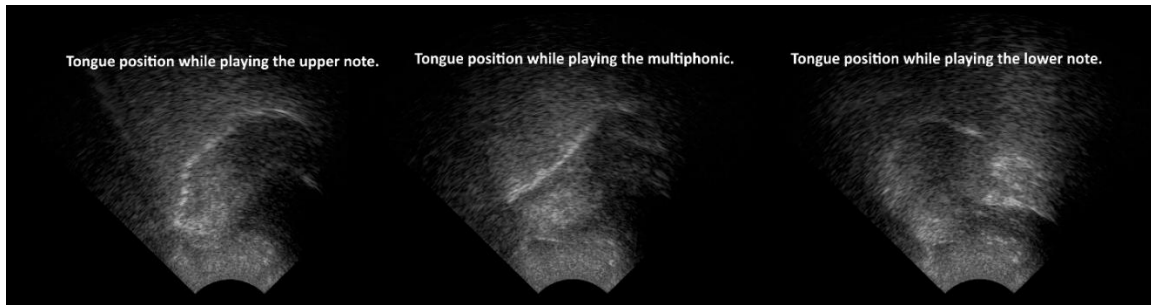


Figure 86. Ultrasound images of Subject G playing multiphonic 1.

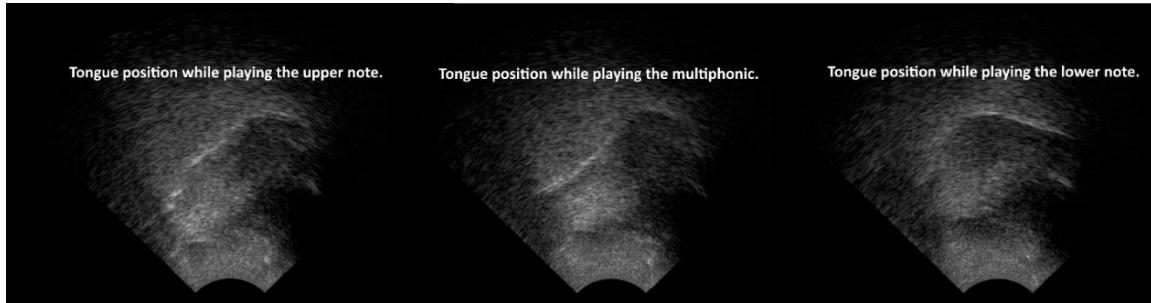


Figure 87. Ultrasound images of Subject G playing multiphonic 2.

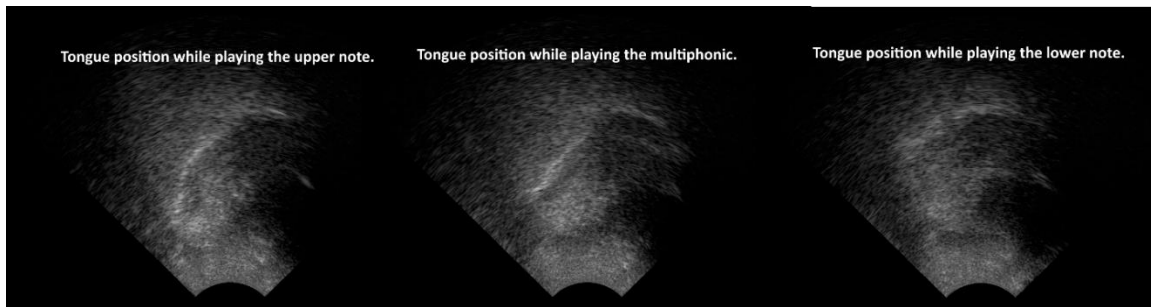


Figure 88. Ultrasound images of Subject G playing multiphonic 3.

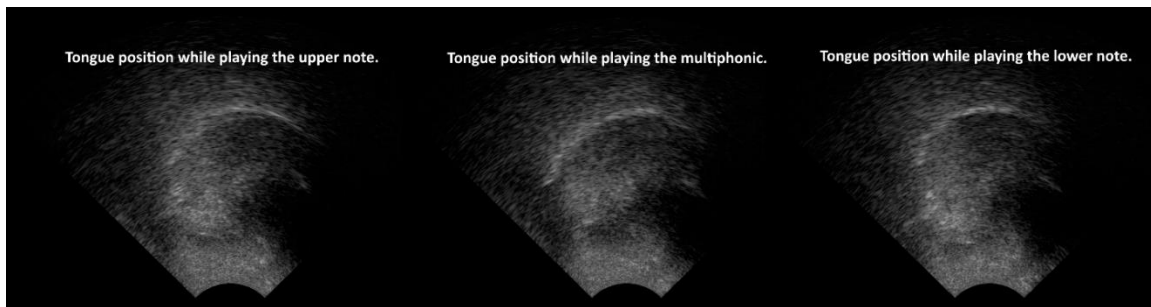


Figure 89. Ultrasound images of Subject G playing multiphonic 4.

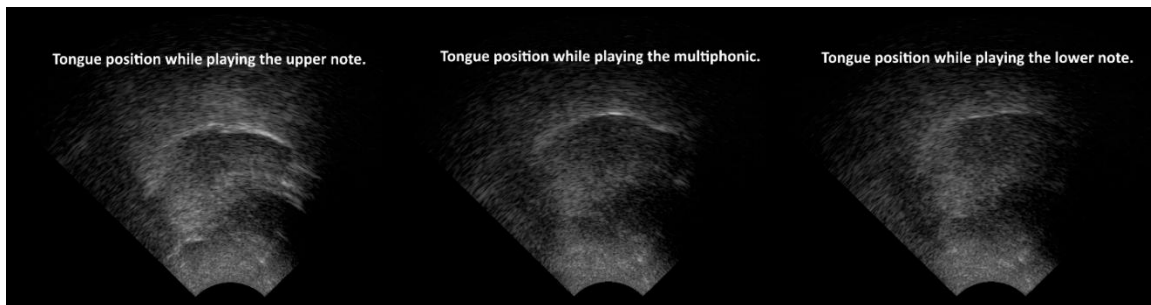


Figure 90. Ultrasound images of Subject G playing multiphonic 5.

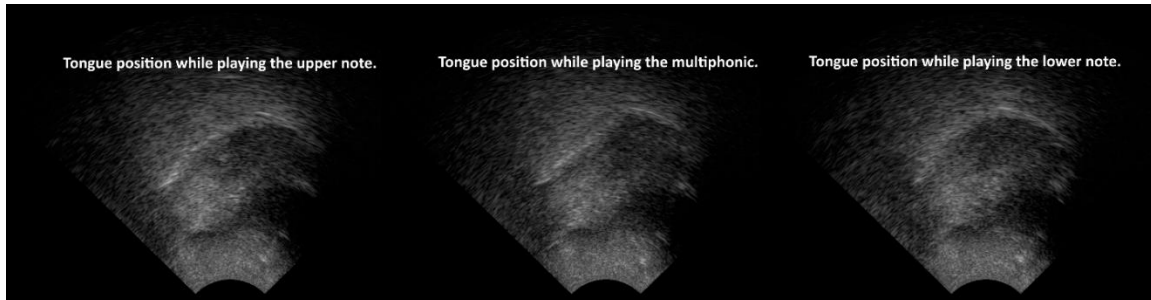


Figure 91. Ultrasound images of Subject G playing multiphonic 6.

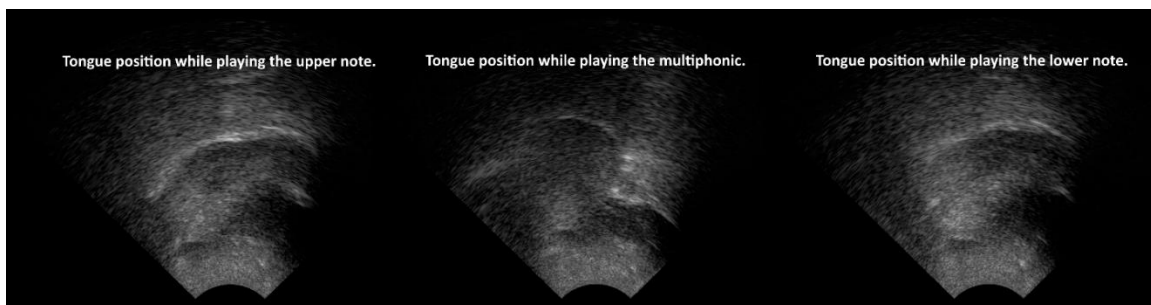


Figure 92. Ultrasound images of Subject G playing multiphonic 7. Subject had difficulty sustaining multiphonic.

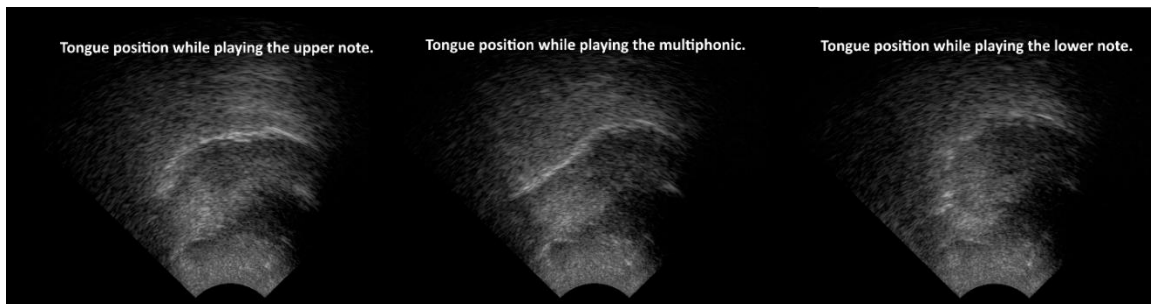


Figure 93. Ultrasound images of Subject G playing multiphonic 8.

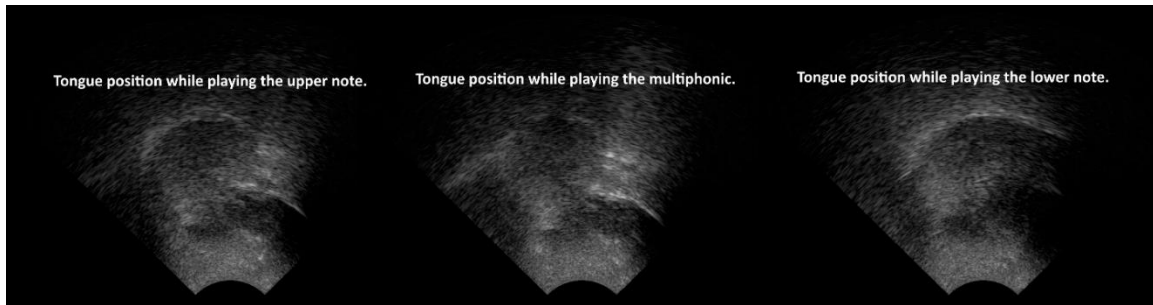


Figure 94. Ultrasound images of Subject G playing multiphonic 9.

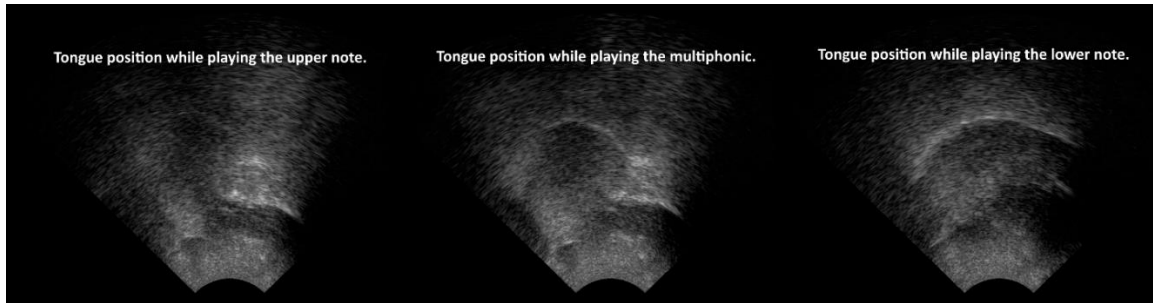


Figure 95. Ultrasound images of Subject G playing multiphonic 10.

Note: Subject G does not always play notes above C6 with the same tongue position when asked to play the note multiple times, such as when playing the upper note and multiphonic of multiphonics 7, 9, and 10.

APPENDIX K

ULTRASOUND IMAGES OF SUBJECT H

Equipment used by subject H:

Clarinet: Buffet R13 Greenline

Barrel: Paulas + Schuler Zoom Barrel, all Delrin, adjustable length

Mouthpiece: David McClune DM8

Ligature: Kasper, brass

Reeds: Gonzalez GD 3.25

Previous experience with multiphonics:

Subject has extensive experience with multiphonics.

Subject did not use the provided instructions and learned to produce the multiphonics based on past experience.

Depth of ultrasound images collected for this subject: 9cm

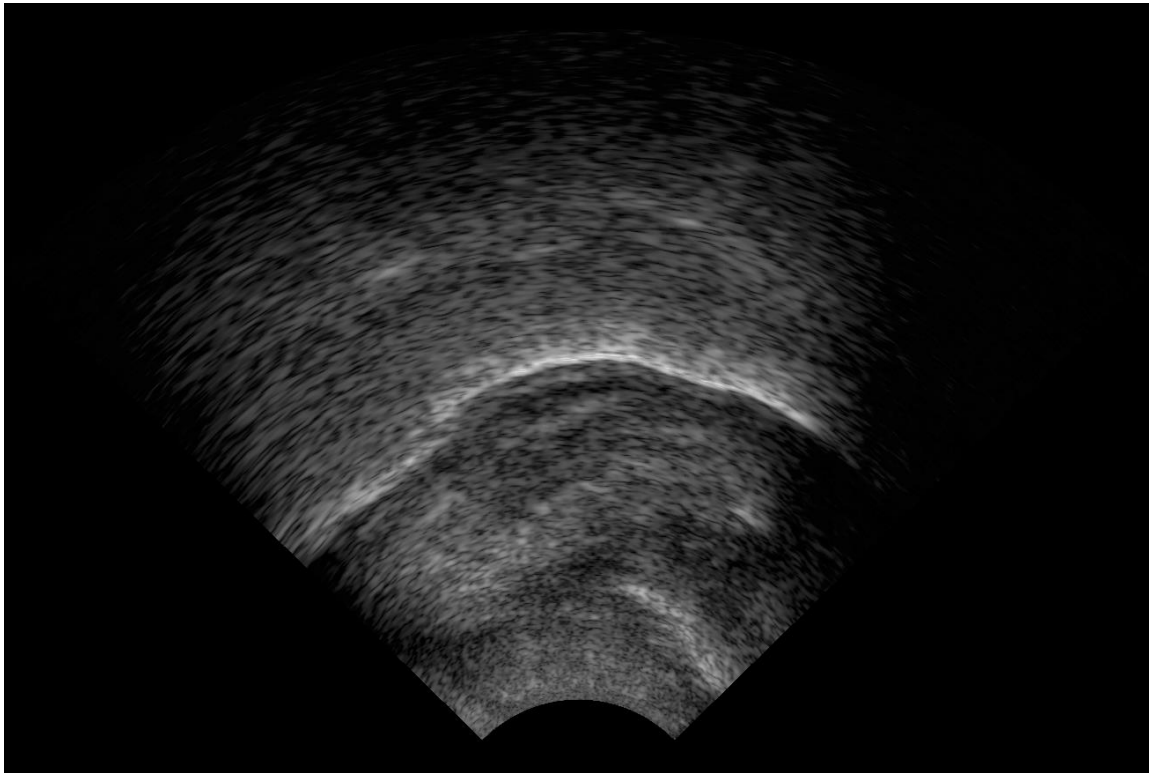


Figure 96. Ultrasound image of Subject H's tongue at rest.

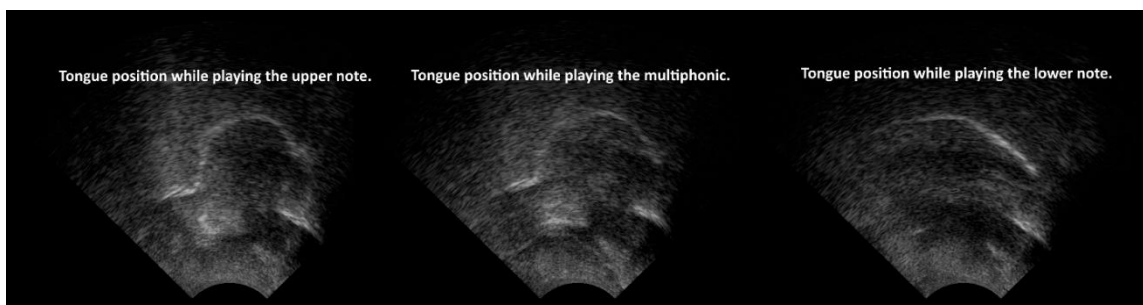


Figure 97. Image of Subject H playing multiphonic 1.

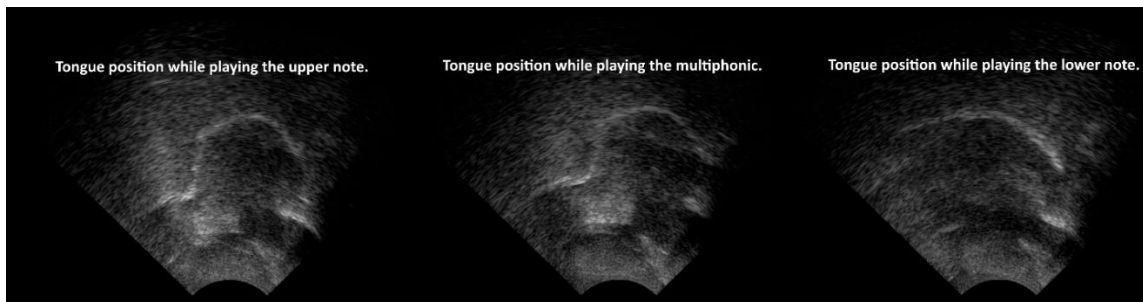


Figure 98. Ultrasound images of Subject H playing multiphonic 2.

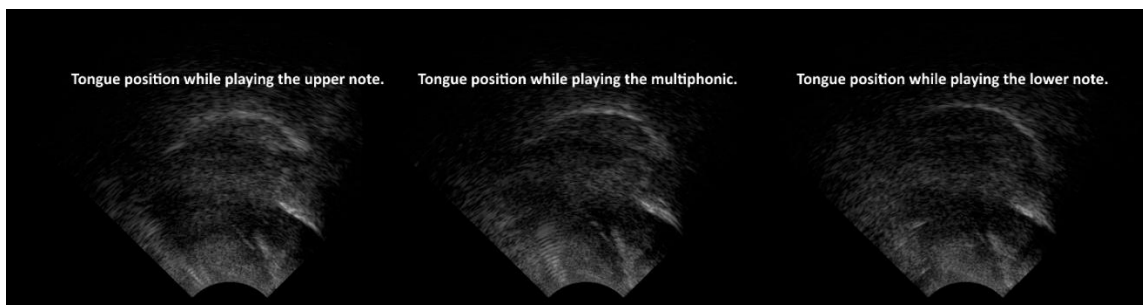


Figure 99. Ultrasound images of Subject H playing multiphonic 3.

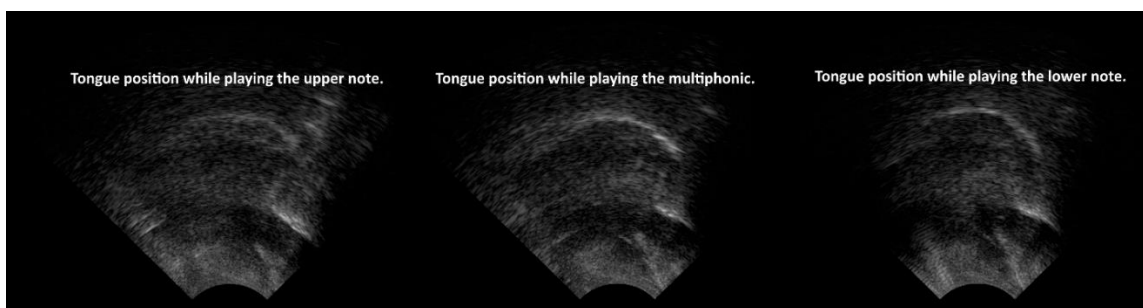


Figure 100. Ultrasound images of Subject H playing multiphonic 4.

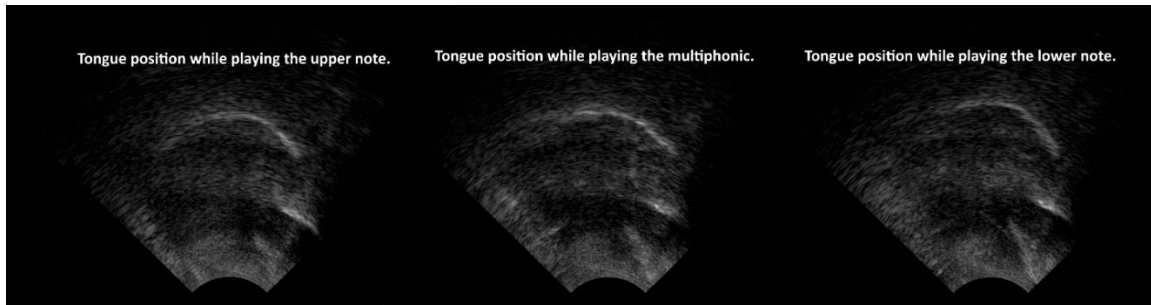


Figure 101. Ultrasound images of Subject H playing multiphonic 5.

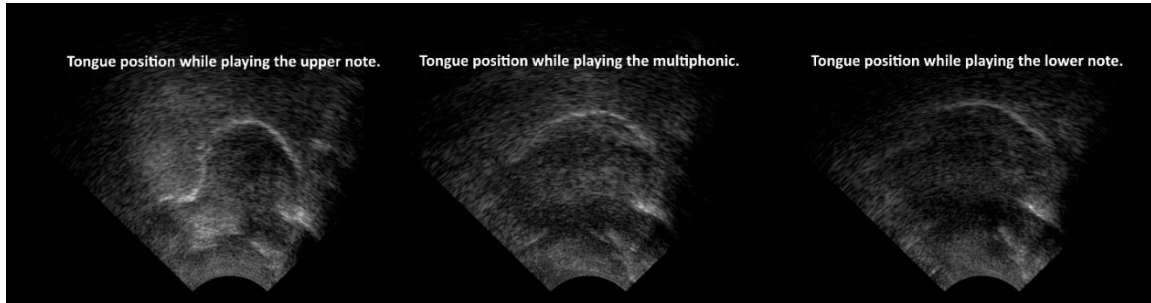


Figure 102. Ultrasound images of Subject H playing multiphonic 6.

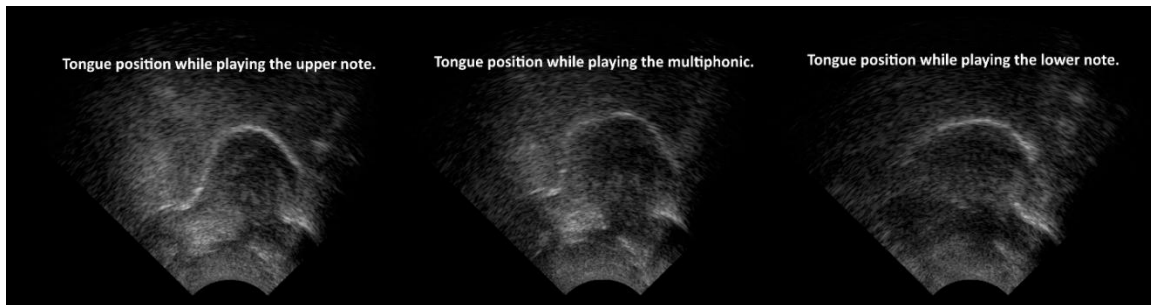


Figure 103. Ultrasound images of Subject H playing multiphonic 7.

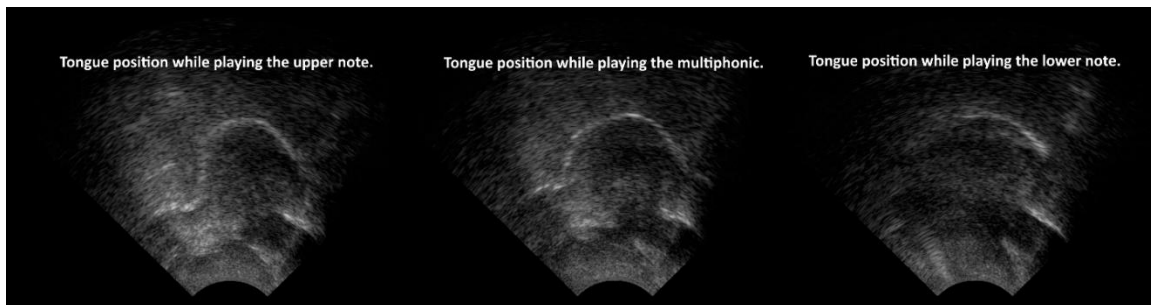


Figure 104. Ultrasound images of Subject H playing multiphonic 8.

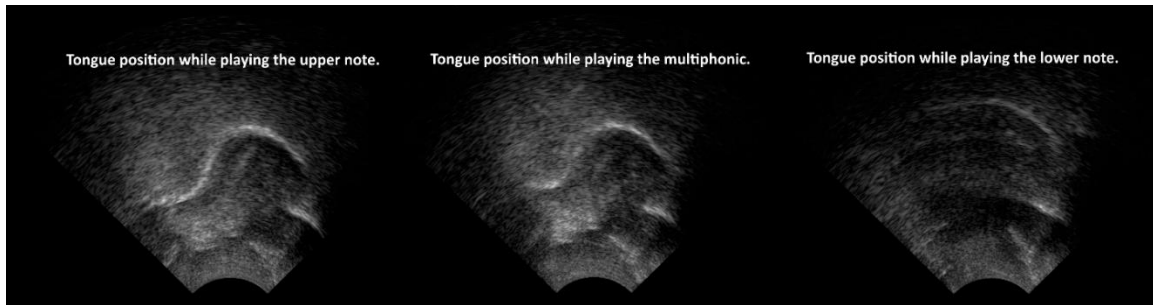


Figure 105. Ultrasound images of Subject H playing multiphonic 9.

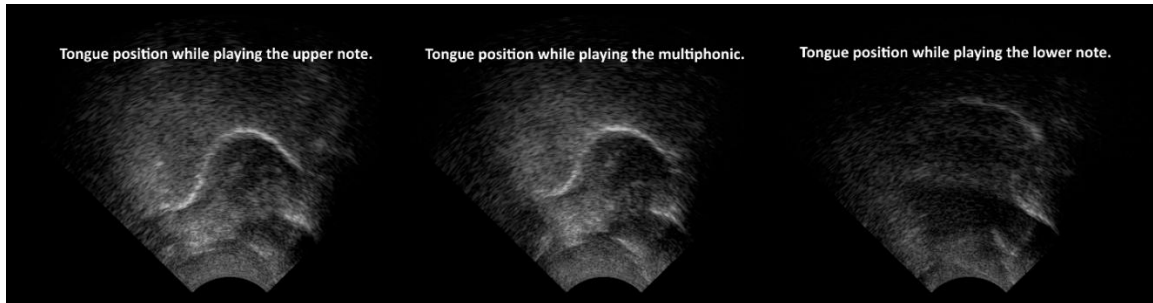


Figure 106. Ultrasound images of Subject H playing multiphonic 10.

Note: Subject H encounters multiphonics in repertoire frequently. Due to this subject's previous experience with multiphonics, the subject did not need to approach the multiphonic from either the upper or lower note. The subject was able to produce both pitches of the multiphonic simultaneously.

APPENDIX L

IRB APPROVAL



APPROVAL:CONTINUATION

Joshua Gardner
Music, School of
-
Joshua.T.Gardner@asu.edu

Dear Joshua Gardner:

On 5/24/2017 the ASU IRB reviewed the following protocol:

Type of Review:	Continuing Review
Title:	Ultrasound Examination of Tongue Behavior during Wind Instrument and Vocal Performance
Investigator:	Joshua Gardner
IRB ID:	1205007871
Category of review:	(4) Noninvasive procedures, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	<ul style="list-style-type: none">• 1205007871.pdf, Category: IRB Protocol;• PPRL_Parental Consent_update5-10-13.pdf, Category: Consent Form;• PPRL_Child Assent_update5-10-13.pdf, Category: Consent Form;• PPRL_Informed Consent_update5-10-13.pdf, Category: Consent Form;

The IRB approved the protocol from 5/24/2017 to 6/2/2018 inclusive. Three weeks before 6/2/2018 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If continuing review approval is not granted before the expiration date of 6/2/2018 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

BIOGRAPHICAL SKETCH

Jack Liang is a freelance musician currently residing in the greater Phoenix area. He has performed throughout the United States and Canada as a soloist, chamber musician, and as a member with various regional symphony orchestras. As a performer, Liang enjoys performing works of all musical styles, with a special interest in contemporary music. His interest in contemporary music has led to the exploration of new sonic and performance possibilities for the clarinet. As an educator, Liang has given masterclasses at Northern Arizona University in Flagstaff, AZ and Glendale Community College at Glendale, AZ. He also maintains a private studio in the greater Phoenix area and offers private lessons and chamber coachings to undergraduate students at Arizona State University. Liang is also a member of the Ambassador Trio, a trio dedicated to popularizing and expanding repertoire for any combination of three instruments from the clarinet family. The trio has performed at several of International Clarinet Association's *ClarinetFest*, hosted the event *Beyond the Frontier: Music of Eric Mandat and William O. Smith*, performed as guest artists at Northern Arizona University and Phoenix Musical Instrument Museum. The trio has also commissioned numerous works since its inception in 2013. Liang received a Doctor of Musical Arts degree in 2018 and a Master of Music in 2015, both from Arizona State University, under the tutelage of Robert Spring and Joshua Gardner. He also received a Bachelor of Music degree in 2013 from University of British Columbia, where he studied with Cris Inguanti.