Acoustic and Perceived Effects

of the Flute's Stopper Mechanism

by

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ABSTRACT

Although many of the effects of the flute's design and mechanisms have been previously studied, the flute's stopper remains relatively unexplored. Stoppers are traditionally made of cork, are used to seal the upper end of the headjoint tubing, and determine the overall intonation of the flute. However, new stoppers made of different types of materials have been created to serve an additional purpose: to improve various aspects of player performance. These new non-cork stoppers vary in design and material, and claim to improve players' projection, resonance, response, and other qualities.

This research project discusses the history of the flute's stopper and its functions, usage, and effects to improve general stopper knowledge and assist flutists interested in trying or purchasing non-cork stoppers available today. Because only three small studies have been published on the stopper's acoustic and perceived effects to date, two single-blind experiments were conducted to determine the stoppers' potential acoustic and perceived effects on listener and player perception. Five of the most popular stoppers available today were tested: the Bigio Stopper, Celestine Rexonator, Seidman Flute Stopper Plug, Swap-Stopper, and the traditional cork stopper.

To determine the stopper's acoustic effects, which can be quantified, an acoustic experiment was conducted to investigate the stoppers' effect on intensity in decibels (which correlates with perceived loudness) and spectral centroid in hertz (which correlates with perceived tonal brightness). Perception tests were conducted to examine how both players and listeners perceive the stoppers' effects on projection, response, tone quality, and timbre. The results of these experiments will

help flutists better understand the effects of the stopper and navigate the stopper-makers' claims about non-cork stoppers available for purchase today.

DEDICATION

For Candace

ACKNOWLEDGEMENTS

My deepest heartfelt thanks go to Elizabeth Buck, Joshua Gardner, and Kay Norton for their support and guidance as I undertook the new and challenging endeavors included with writing this document. Without their encouragement, reassurance, and expertise, this experiment and paper would not have been possible. To my mentor, Elizabeth Buck, thank you for 6 years of invaluable instruction and compassion as an extraordinary musician, teacher, and friend. Thank you for believing in me every step of the way. To Joshua Gardner, thank you for enthusiastically helping me turn a crazy experiment idea into reality with your study experience and equipment. Kay Norton, I thank you for sharing your writing and formatting expertise. Thank you all for your time and willingness to be on my committee.

Thank you to all of the flutists worldwide who participated in my stopper usage survey, to the flutists and stopper-makers who donated their time and loaned me their stoppers, to the Arizona State University flute studio who listened to my rigorous listening test, to Clarke Rigsby for letting me use your recording space, and most of all, to the incredible flutists who generously gave their time to this experiment by play testing the stoppers.

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To my favorite engineers: My husband, Ross Kerley, and my dad, Stephen Hoeckley, thank you for the many enthusiastic brainstorming sessions that led to the experiments I conducted. Thank you to my mom, Rhonda Hoeckley, and my sister, Candace Hoeckley, for your endless encouragement and patience as I weathered and navigated all of the emotions a project of this magnitude evoked. To my family, I could not have completed this paper without your love, compassion, and positivity. Thank you for believing in me.

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CHAPTER 1

INTRODUCTION

When we flutists breathe life into our instruments, a wonderful range of beautiful sounds can emerge. They can express qualities such as elegance, power, unease, desolation, or tranquility. While much of the quality and essence of that sound arises from a flutist's own skills (breath control, embouchure and oral cavity setup, level of musicianship, interpretation of phrases, for example), at the core of that sound are the acoustic qualities from the physical design of the flute itself, and how each component of that design influences the sound.

Since Theobald Boehm's revolutionary re-design of the flute in 1847—in which he redesigned the spacing of the tone holes (the Schema), designed the parabolic headjoint, and created the cylindrical bore—we understand much more about the acoustic impact of flute design. The design has been studied in depth, and that understanding has led to the beautifully sophisticated instruments available to flutists today. For all the study of the design, however, one component of sound production in the flute remains relatively unexplored: the effects of the "stopper." The stopper (also known as the "stopper mechanism," "crown assembly," or "plug") is the material that seals the top end of the flute's headjoint and determines the length of the tubing for intonation purposes (see Figure 5).

The term "stopper" generally does not include reference to the "crown," although the terms "stopper mechanism" and "crown assembly" do include the crown, especially when a stopper is designed to work in tandem with a specific kind of crown.[1] Acoustically, the stopper both absorbs vibrations and reflects the sound towards the open end of the flute at the footjoint.

Traditionally, new flutes include a cork stopper and a metal crown. However, there are a surprisingly large number of non-cork stoppers available (though not all widely used) made of a variety of materials such as metal, plastic, rubber, and even cattle calf bone.[2] The makers of these stoppers and stopper mechanisms claim their products improve the tone and other flute properties. The questions those claims raise are: *How* does a particular stopper material improve tone and other properties, *in what way*, and *to what degree*?

There have been a few flute stopper studies conducted, but very little academic research published about the acoustic and perceived effects of the stoppers that have been developed within the last 30 years. The information available raises more questions than it answers. When I discovered that prominent stopper maker Robert Bigio was asked, "Why do [your stoppers] work?" and he replied, "I'm honestly not sure,"; I chose to research flute stoppers to add to the body of knowledge.[3]

To do this, I designed and conducted two single-blind stopper experiments: (1) an acoustic test to study the effects on the sound, and (2) a human perception test to determine what listeners and players are perceiving in the sound. I conducted the experiments using five popular stoppers available today.

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[1] "Stopper mechanism" and "crown assembly" both refer to the stopper and the crown as one unit or mechanism.
[2] "Stoppers," CE Flute, accessed March 24, 2020, http://www.ce-flute.eu/en/stoppers/.
[3] Robert Bigio, "Stoppers and Crowns," accessed March 24, 2020, http://www.bigio.com/stoppersandcrowns.htm.

In this paper, I review the available literature on flute stoppers and note the gaps and unanswered questions. I then provide the details on the general stopper usage survey and two single-blind experiments I conducted, how and why they were designed, and their results. Lastly, I include notes about further stopper research which may be useful for others to study in the future.

CHAPTER 2

HISTORY OF THE STOPPER

Ancient Stoppers

Flute stoppers may be nearly as old as the flute itself. According to writer Sally Banks, stoppers have been around for at least 30,000 years.[4] Clay stoppers were used in bone flutes with the "fipple" design, where the air stream is directed into a channel and onto the beveled edge of a sound hole (see Figure 1).[5] These fipple flutes were sealed at one end with a stopper to direct the pulse of high pressure that creates the standing wave past the tone holes.

Jelle Atema, a flutist and professor of biology at Boston University, made a working copy of a 50,000-year-old Neanderthal flute with a fipple-design mouthpiece that required a specific design of stopper (see Figure 1).[6] The original flute from which he modeled his copy was discovered in 1995 in the Divje cave (also known as Divje Babe) near Lubiana, Slovenia, and was crafted from the femur bone of a young bear. Atema says that the Neanderthals could create more sophisticated sounds with fipple flutes, which were more difficult to produce than open-ended flutes (such as the pan flute).

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[4] Sally Banks, "Sweet Sounds Waft from Fipple Flutes," *Calgary Herald*, March 15, 1992, http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/244162997?accountid=4485.

[5] The "fipple" design is much like that of a recorder.

[6] Jelle Atema, "Science Association Conference: Neanderthal Man Played the Recorder," *The Independent*, February 21, 2000, http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/311603674?accountid=4485.

Figure 1. Divje Babe Flute[7]

<u>Baroque Flute Stoppers</u>

Centuries later in the Baroque era, Johann Joachim Quantz references a stopper that he calls a "cork plug" in his famous treatise *On Playing the Flute*.[8] He recommends that flutists attach a screw to the cork so its position can be changed more easily. Johann George Tromlitz, an 18th-century flutist and flute-maker, calls this development a "screw cork" and attributes its invention to Quantz.[9] This would make sense, since some of the earliest modifications to the Baroque flute were created by Quantz (such as the E-flat key and the two-part headjoint that became our modern tuning slide), but the truth of this attribution is unclear. Antoine Mahaut attributes it to Gabriel Buffardin in his treatise, *A New Method for Learning to Play the Transverse Flute*.[10] To muddy the waters further, Henry Macaulay Fitzgibbon states in his book, *The Story of the Flute*, that Quantz never

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[7] Narodni Muzej Slovenije, "Neanderthal Flute," accessed on April 20, 2020, https://www.nms.si/en/collections/highlights/343-Neanderthal-flute.
[8] Joachim Quantz, *On Playing the Flute* (New York: Schirmer Books, 1966).
[9] Johann Tromlitz, *The Keyed Flute* (New York: Oxford University Press, 1996).
[10] Antoine Mahaut, *A New Method for Learning to Play the Transverse Flute* (Bloomington: Indiana University Press, 1989).

claims to have invented the screw cork, and it is true that Quantz does not claim the idea in his treatise.[11] It is possible that Tromlitz was mistaken, or perhaps Quantz and Buffardin invented the same idea, separately.[12]

Regardless of the inventor of the screw cork, the cork stopper was used in Baroque flutes to assist with tuning while playing softly. "The screw section of the head-joint tenon was to be turned to make the head-joint shorter" (which would raise the pitch). As Andrew Fairley writes in his book *Flutes, Flautists and Makers: Active or Born Before 1900*, "the method of playing at that time was to cover more of the tone hole with the lips, but this had the undesirable effect of flattening the intonation."[13]

Stoppers in the 8-Key and Boehm Flute

Very little changed in the cork stopper's design as the Baroque flute developed into the 8-keyed flute, and later the Boehm flute. In particular, the cork stopper used in Boehm flutes does not look much different from cork stoppers used today (see Figure 2).[14] The stopper's function as a tuning mechanism remained, and its specific location in the headjoint is detailed in two of the great flute treatises by Boehm and Rockstro.[15] [16] Additionally, Boehm recommended removing the cork after

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[11] Macaulay Fitzgibbon, *The Story of the Flute* (New York: William Reeves, Bkseller, ltd., 1914).
[12] Fitzgibbon, *The Story of the Flute*.
[13] Andrew Fairley, *Flutes, Flautists and Makers: Active or Born Before 1900* (London: Pan Educational Music, 1982).
[14] Rick Wilson, "19th Century Boehm Flutes," accessed March 24, 2020, http://www.oldflutes.com/boehm.htm.
[15] Theobald Boehm, *The Flute and Flute-Playing in Acoustical, Technical, and Artistic Aspects* (1871), Translated by Dayton C. Miller (New York: Dover, 1964).
[16] Richard Shepherd Rockstro, *A Treatise on the Construction, the History, and the Practice of the Flute*, (1928) 2nd ed., Translated by Georgina M. Rockstro (London: Musica Rara, 1967).

each use to swab the instrument thoroughly so the wood does not warp.[17] As the flute developed into a metal instrument, however, this practice was not continued. Flutists today rarely interact with the cork stopper in their instrument, beyond checking its location and having a repair technician replace it annually or when it dries out or shrinks.

Figure 2. Cork Assembly on the Boehm Flute by Meinell

Early-Twentieth Century Stoppers

In the twentieth century, the biggest development in the stopper was the invention of the O-Ring, created by Rudall, Carte & Company and used in wooden flutes in the early 1900's.[18] This stopper was made of neoprene, a synthetic rubber, and can be considered the first non-cork stopper. Neoprene was found to have a tighter seal than cork stoppers, which were prone to shrinkage. It was adapted to better fit the silver flute by English headjoint maker Leslie Eggs in the 1970's, and was imported to the United States by James Pellerite, a renowned flute performer,

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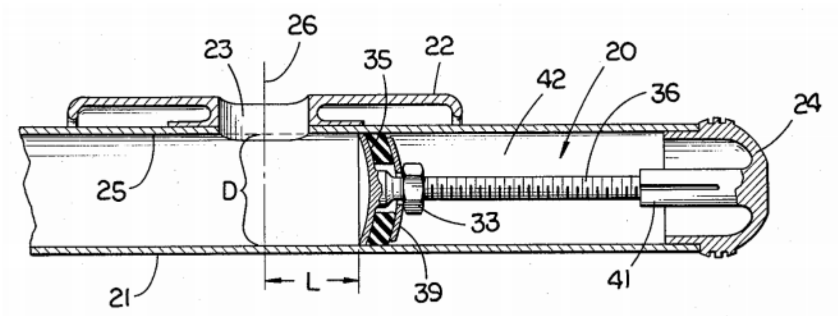
[17] Theobald Boehm, *The Flute and Flute-Playing in Acoustical, Technical, and Artistic Aspects.*
[18] Nancy Toff, *The Flute Book: A Complete Guide for Students and Performers. 2nd ed.* (Oxford: Oxford University, 1996), 61.

teacher, co-founder of the National Flute Association, and proprietor of Zalo Publications and Services, who owns the patent (see Figure 3).[19]

Figure 3. Pellerite's O-Ring Design

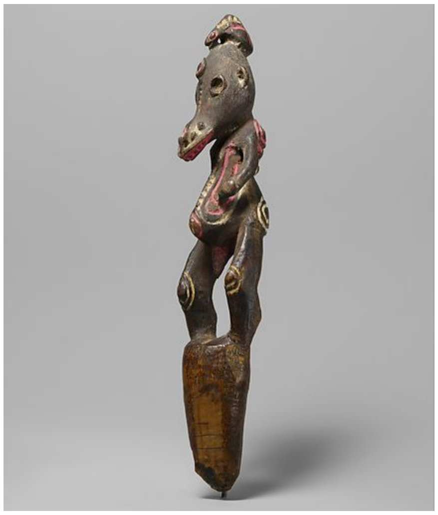


Stoppers in Non-Western Flutes

As an interesting side note, in Papua, New Guinea, stoppers are the "most impressive and most sacred" part of the flute.[20] What would be the crown and stopper of a Western flute are combined in these bamboo flutes. These intricate and often embellished stoppers are carved to represent humans, animals, or bird totems (see Figure 4).[21] They are considered protective because they prevent inadvertent summoning of evil spirits.

[19] James Pellerite, Headjoint Stopper, US Patent 4,240,320, filed March 21, 1980, issued December 23, 1980, and expired November 27, 1998.
[20] Christina Hardy, "Instrument of the Spirits," *The Nelson Mail*, October 12, 2013, 15, accessed on March 24, 2020, https://search-proquest-com.ezproxy1.lib.asu.edu/docview/1441442712/CF6971AC2D1B412EPQ/2?accountid=4485.
[21] "Flute Stopper," The Metropolitan Museum of Art, accessed March 24, 2020, https://www.metmuseum.org/art/collection/search/313775.

Figure 4. Papua New Guinean Flute Stopper (Early 20th-Century)



In Western music, stoppers are far less decorative and spiritual. Stoppers in the Western concert flute are intended to serve a practical purpose, and are made of a variety of materials intended to enhance different properties of the flute's tone, projection, and response.

<u>Current Flute Stoppers</u>

Historically, transverse flutes have been made with cork stoppers ever since the Baroque Era. Unlike the pan flute and the Shakuhachi, in which the open end of the tube is blown across like a bottle, the blowing hole of the transverse flute is farther down the instrument. The top end of the flute is sealed with a stopper so the air is forced to travel past the tone holes, instead of also escaping out the top end of the headjoint. The design of transverse flutes is more technologically sophisticated than the early flutes, and allows for more customization of the size of the embouchure hole and the blowing angles where the air enters the flute.

The traditional cork stopper today comprises a cork, threaded rod, nut, and flat metal disc (see the top stopper in Figure 5). As Cleo Leung succinctly describes, "the rod is threaded through the center of the cork and soldered or welded to the cylindrical disc such that the bottom of the cork is flush with and glued to the disc. The nut is then screwed down against the cork."[22] This bottom disk is what is visible when you look in the open end of the headjoint, which must be placed in the correct location relative to the center of the embouchure hole for intonation purposes. This location can be checked with the tuning rod supplied with every flute. The non-slotted end of the tuning rod is inserted into the headjoint, and the stopper location is correct when the line on the rod is centered between the left and right side of the embouchure hole. When the line is centered in the embouchure hole, the distance between the stopper and the center of the embouchure hole should measure 17.3 mm.

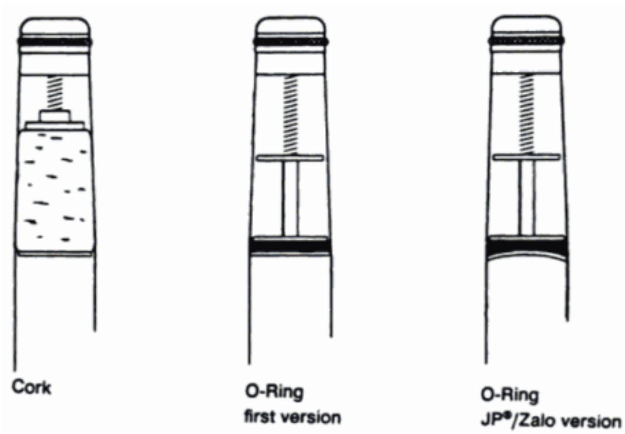
Figure 5. Crowns (left) and Stoppers (right) and Their Location in the Flute[23]

[22] Cleo Leung, "Overtone Characterization of Garner Headjoints Using Spectrographic Analysis and Fast Fourier Transforms" (DMA diss., University of Cincinnati College-Conservatory of Music, 2011).

[23] Stephanie Hoeckley, "Flute Stopper Mechanism," photo, April 24, 2020.

Most stoppers have a flat internal surface or face, such as the cork. Others, such as Pellerite's O-Ring, have a concave surface (see Figure 6).

Figure 6. Flat and Convex Stopper Faces[24]



[24] James Pellerite, Headjoint Stopper.

CHAPTER 3

LITERATURE REVIEW

Despite existing on every standard C flute for more than a century, the stopper remains relatively unaddressed in the available literature from a flute acoustics perspective. This is surprising, because the stopper is vital in sound production on the flute. In this chapter, I will discuss in detail the stoppers which are available today and summarize the existing research on the stopper's effects.

The non-cork stoppers discussed in this chapter are made of many different kinds of materials of varying densities, as shown in Figure 7.[25]

Figure 7. Common and Uncommon Stopper Material and Densities (in g/cm3) (The most commonly-used stopper materials are in bold)

Material	Density (g/cm^3)
Cork	0.24
African Blackwood	1.08
Delrin	1.41
Beryllium	1.85
Aluminum	2.7
Titanium	4.51
Zirconium	6.49
Tin/Copper alloy (96.5%/3.5%)	7.35
Brass	8.55
Copper	8.96

[25] David Symington, "Stopper Sounds," *Pan: The Flute Magazine* 22, no. 1 (March 2003): 16-17.

Material	Density (g/cm^3)
Sterling Silver	10.4
10k yellow gold	11.59
Lead	11.84
14k yellow gold	13.07
Hafnium	13.1
Tungsten/Copper alloy (75%/25%)	14.8
Tantalum	16.1
22k gold	18.56
Tungsten	19.1
Platinum	21.45

Non-Cork Stoppers

Robert Bigio, British flute-maker and performer, makes what is likely the most popular non-cork stopper available today. Eschewing the traditional cork, and common metals like silver and gold, his stoppers are made of either Delrin (hard plastic) or zirconium (see Figure 8).[26] The Bigio crowns designed to be used with his stoppers are made of zirconium or African Blackwood, otherwise known as Grenadilla. Bigio's stoppers are smaller and consume less space inside the headjoint than traditional cork. This allows for more empty space between the stopper and the crown at the top end of the headjoint. As to why his design and choice of materials increase resonance on the flute, even Robert Bigio himself is uncertain. When asked

[26] Robert Bigio, "Stoppers and Crowns."

why his stoppers work, he stated, “I’m honestly not sure. One suggestion is that the space between the stopper and crown (which is normally filled with a cork) acts as a vibration chamber. Another suggestion is that the stopper, which is short, light and held in place only by the O-ring, vibrates with the air column in the flute.”[27]

Figure 8. Bigio Crown (left) and Stopper (right)

Similarly, another British flute-maker, David Symington, emulated Robert Bigio’s designs in 2001, and now produces stoppers made of many different materials. His stoppers and crowns contain materials such as sterling silver, hafnium, tungsten, lead, a copper/beryllium alloy, and a gold/silver alloy (see Figure 9). His stoppers are not necessarily worth mentioning in uniqueness of design, for they use Bigio’s unpatented design, but Symington created many alloys, tested these materials, and published his results in *Pan Magazine*, the Journal of the British Flute Society.[28] These findings are significant for two reasons. One, these results are in a popular and accessible journal, not an acoustics journal; and two, few makers publish material to support their claims. This is not to say that makers are required to elaborate upon how and why their inventions work, but it could help lend

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[27] Bigio, “Stoppers and Crowns.”
[28] David Symington, “Stopper Sounds.”

credibility and lasting success for marketing items that are additional or supplemental to the instrument. Symington's experiments and findings will be discussed in more detail later in this chapter.

Figure 9. Symington Stoppers and Crowns

Other alternative stoppers on the market that feature metals include the Gary Lewis Crown Assembly, the Celestine Rexonator (formerly known as the Rhino Flute Resonator), and the Briccialdi Titanium Stopper Plug. According to American Gary Lewis via his webpage, a "vibrant flute tube…can only achieve its optimal sound through an equally vibrant crown assembly."[29] Lewis created a stopper mechanism with three settings that can control the amount of spring tension in the mechanism. He states that lower spring tension allows for freer vibrations in the flute's tubing. Much of his design information is available on his US Patent page (see Figure 10).[30]

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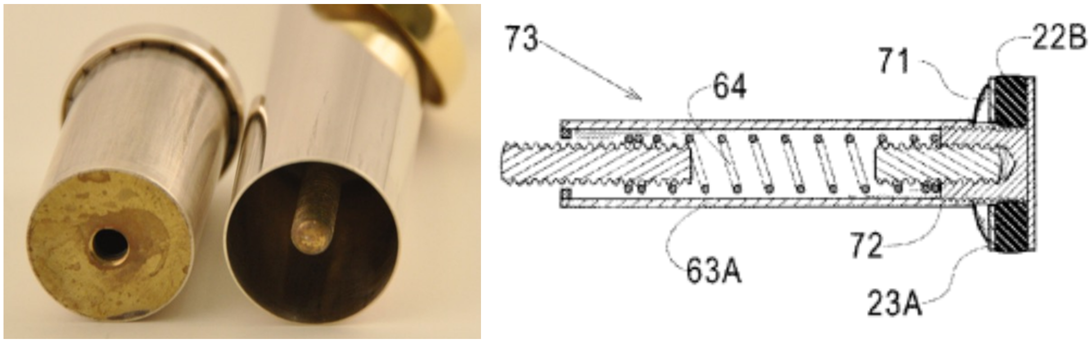
[29] Gary Lewis, "Flute Crown Assemblies," last modified 2016, accessed March 24, 2020, http://www.garylewisflutes.com/index.php?main_page=index&cPath=16.
[30] Gary Wayne Lewis, Headjoint Crown Assembly with Extension Unit, US Patent US8653347B1, filed on August 10, 2012, application published February 18, 2014, and

Figure 10. Gary Lewis Select Crown Mechanism



Another maker to patent his design is Roberto Feliciano, from Puerto Rico, creator of the Celestine Rexonator (see Figure 11).[31] His brass stoppers are available in three different designs: Base, Fit, and Balance. The "Balance" model features four adjustable and removable brass rings to create five different weight options. The "Fit" model is the same as the "Balance," except it includes only two brass rings, and the "Base" model includes none of the rings. The rings on the Celestine Rexonator stoppers allow the flutist to: 1) choose where in the headjoint they place the most weight, and 2) control where the empty space in the headjoint is located. Feliciano recommends that flutists try moving and even possibly removing the weights to determine the setup and sound they prefer.[32]

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application active, accessed on March 24, 2020, http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=8,653,347.PN.&OS=PN/8,653,347&RS=PN/8,653,347.

[31] Roberto Feliciano, Rhino Flute Resonator and Crown, US Patent 10,002,595, filed September 27, 2016, and issued June 19, 2018, accessed on March 24, 2020, http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=8,669,449.PN.&OS=PN/8,669,449&RS=PN/8,669,449.

[32] Roberto Feliciano, "Part 2-3: Rhino Flute Resonator One Ring or Two Ring and Accessories," YouTube video, posted on November 2, 2016, https://youtu.be/vHxWwrMjg-4.

For each of the three models, he also includes rubber O-rings with four different hardnesses that flutists can exchange to change the brightness of the sound. Although he describes the general effect of the different O-rings, he recommends flutists experiment by playing each O-ring and listening carefully to the effect. Many design details and other useful information can be found on Feliciano's U.S. Patent page.

Figure 11. Celestine Rexonator, Balance model

Made in Italy by Flauti Briccialdi, the Briccialdi Titanium Stopper Plug advertises different features than many of the American or British stopper mechanisms (see Figure 12). Instead of encouraging players to improve their tone with heavier materials, as in the United States or England, the Briccialdi stopper advertises a lighter material, claiming that their stopper is important because it "reduces the stopper overall weight," although it is certainly heavier than cork.[33] Another notable difference about this stopper mechanism is that it is connected to the included crown. The other stoppers available either connect to a traditional

[33] "Briccialdi Titanium Stopper Plug," Briccialdi Flutes Italy, accessed March 24, 2020, https://www.briccialdi.it/.

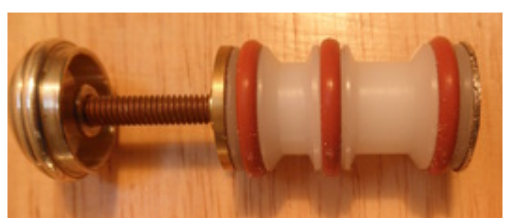
crown with the threaded rod (such as the Celestine Rexonator) or are completely separate (such as the Bigio Stopper and Crown).

Figure 12. Briccialdi Titanium Stopper Plug

Despite its popularity as a material, not all alternative stoppers are made of metal. Two lightweight plastic stoppers made of Delrin are also available, both invented by American stopper makers. The Performance Flute Plug was invented by Bob Ogren more than 20 years ago (Figure 13) and, similarly, the Seidman Flute Stopper Plug was invented by Mark Seidman in 2009 (see Figure 14). Both Delrin stoppers are intended to be used with a normal crown and look much like plastic wine corks. The shape of each of these stoppers is slightly different, and the Seidman Flute Stopper Plug uses three O-rings, while the Performance Flute Plug uses two.

Figure 13. Performance Flute Plug

Figure 14. Seidman Flute Stopper Plug



Another alternative, the Swap-Stopper, does not fit so easily into one category of material (see Figure 15). Invented by Peter Robertson in the UK in 2017, its most distinguishing feature is the ability to "swap" the metal faces, which are each made of zirconium, sterling silver, and titanium. The stopper base is made of plastic, but also includes three metal faces and two weights that all magnetically attach to the stopper. The stopper is made of plastic and the O-rings form a tight seal in the tube, but the three faces can be exchanged easily without needing to remove the stopper. The kit includes a long tube with a magnet on the end, which can be inserted into the headjoint and allows the stopper faces to be exchanged quickly and easily.

For additional personalization, two magnetic weights can be attached to the top of the stopper, underneath the crown. Robertson took flute-making classes with Robert Bigio and intended his stopper to be used with Bigio crowns.

Figure 15. Swap-Stopper

Hungarian Zoltán Lakat of C.E. Flute Stoppers has created more than 20 stoppers of varying materials and designs, although I have not yet found a flutist who uses them.[34] C.E. Flute Stoppers includes specific claims about each product. Materials include doe antlers, cow calf bone, silver, brass, 14k gold, zirconium, ebony, cocobolo, bronze, and rhodium. Examples of the four designs are shown below (see Figure 16). The stopper on the far right includes disks for extra mass, and the bottom-left stopper includes an extra insert between the stopper and the crown.

Figure 16. C.E. Stopper Designs

Though the Celestine Rexonator and the Gary Lewis Flute Crown Assemblies both have current patents that are being used for manufacture, three patents exist for products that are no longer in production: (1) James Pellerite's O-Ring (as mentioned earlier),[35] (2) French stopper maker Ernest Ferron's Logicork stopper,[36]

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[34] "Stoppers," CE Flute.

[35] James Pellerite, Headjoint Stopper.

[36] Ernest Ferron, Obturator for Flute Designed to Improve the Emission of Certain Notes, US Patent 4,499,810, filed June 21, 1983, issued February 19, 1985, and expired on June 21, 2003, accessed on March 24, 2020, http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4,499,810.PN.&OS=PN/4,499,810&RS=PN/4,499,810.

and (3) the Dutch Dyna Flute System, which was included in a couple of experiments that will be discussed later in more detail (see Figure 17).[37] Lastly, one other stopper exists that is neither presently produced and was never patented. Gran Partita's G.P. Sprinter was created in Italy in 2011 (see Figure 18).[38]

Figure 17. Dyna Flute System

Figure 18. G.P. Sprinter

Stopper Details and Claimed Selling Points

As to be expected with any product for sale, non-cork stoppers are advertised with claims that they provide significant improvements over traditional cork stoppers. The stoppers' selling points and testimonials can be found on the individual stoppers' online websites. These sources may not be academic, but they are important because the makers of different stopper mechanisms can directly reach and instruct the greater public about their products. The makers' claims include improvement of many of the challenges with which flutists commonly struggle (see Figure 19).

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37 Michel Parmenon, Flute, US Patent 2007/0272071A1, filed September 2, 2004, application published November 29, 2007, and application abandoned, https://patents.google.com/patent/US20070272071A1/en?q=flute&inventor=parmenon&oq=parmenon+flute.
38 "New Products," *Flutist Quarterly* 37, no. 1 (Fall 2011): 64-66. Accessed on March 24, 2020, http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/902666361?accountid=4485.

Figure 19. Materials, Claims, and Cost of Available Stoppers

Stopper Name	Materials	Claims to Improve	Approx. Cost (USD)
Bigio Stopper	Zirconium, 1 O-ring	Sound/Resonance Response Loudness/Projection Smoothness	$400
Briccialdi Titanium Stopper Plug	Titanium, 1 O-ring	Ease in the low register 2nd and 3rd octave responsiveness	$110
C.E. Flute Stoppers[39]	Various materials (20 materials and designs), 1-2 O-rings	Sound/Resonance Response Loudness/Projection Precise, effortless staccato articulation Low register power Stable E6 Clarity Extreme dynamics Quantity of air accommodated	$80-$215
Celestine Rexonator	Brass alloy, 1 O-ring	Sound/Resonance Response Loudness/Projection Stable articulation More control Dynamic range Vibration "Almost impossible to crack a note"	$100-$200
Gary Lewis Select Crown Mechanism	Sterling silver	Sound/Resonance Response Smoother legato lines and interval jumps Quicker articulation Refined third register	$695

[39] "Stoppers," CE Flute.

Stopper Name	Materials	Claims to Improve	Approx. Cost (USD)
Symington Flutemet	Metal alloy, 1 O-ring	No specific claims “Marked results” “Changes playing characteristics of the headjoint” “Pleasing and novel results”	$225
Performance Flute Plug	Delrin, 3 O-rings	Loudness/Projection Response Clarity/Focus	$20
Seidman Flute Stopper Plug	Delrin, 3 O-rings	Sound/Resonance Response Clarity/Focus Control Stable E6 Ease Vibration	$25
Swap-Stopper	Plastic, 3 O-rings, 3 removable metal faces, 2 metal weights	Loudness/Projection Smoothness Articulation Evenness across registers	$245

Additional selling points listed on stopper websites include claims made by professional players and the makers themselves. The testimonials give some insight into which players are using them, and what these players are perceiving. Here is an example of a testimonial about the Celestine Rexonator from Stephen Clark, winner of the 2018 Alexander and Buono International Flute Competition:

> Last August [Roberto] asked me to try it and fitted it to my headjoint and I immediately realized this was the future. Everything about my flute improved. EVERYTHING. You can definitely feel a difference in weight. It took me about a day to get used to it. Some people want darker sound. There is [ring] position for that. I wanted more sparkle

and brilliance and it absolutely gave me that. Also, much crisper articulation and projection. Seriously amazing![40]

Other professional flutists who have given testimonials about the Celestine Rexonator include Tracy Harris, a Yamaha Performing Artist, and José Valentino Ruiz, a Latin Grammy-nominated artist and composer. The Celestine Rexonator website makes the highest number of claims of all of the stoppers included in this study. Feliciano claims that his stopper improves projection and vibrations, enhances resonance, expands the dynamic range, stabilizes articulation, improves response, makes the technical control of the vibrato easier, uses new technology that gives players more control, and that it is almost impossible to crack a note.

Like the Celestine Rexonator, the Seidman Flute Stopper Plug also includes the maker's claims and testimonials on the product's website. Seidman states that cork "deadens" the sound of the flute, and his stopper's "reflective" material (Delrin) resists the absorption of sound waves. The website also includes dozens of testimonials from satisfied customers, including one from Marco Granados, a Haynes Performing Artist. He shares his experience on the Seidman website:

> [The Seidman Stopper Plug] is incredibly useful both from the perspective of sound and the reliability of the headjoint in different climate conditions. I noticed that your stopper minimized the amount of tension or distortion created by the cork in the sound. The sound is definitely more consistent through the full range of the flute. I highly recommend it.[41]

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[40] "Celestine Flute Rexonator," RFRolon, accessed March 24, 2020, https://www.rfrolon.com/product/celestine-flute-rexonator-balance.
[41] "Feedback/Reviews," Seidman Flute Technology, accessed March 24, 2020, http://www.seidmanflutetechnology.com/feedbackreviews.html.

Although Robert Bigio does not share testimonials about his stopper, he does share his thoughts on why his stopper works, as was noted previously: "One suggestion is that the space between the stopper and the crown (which is normally filled with a cork) acts as a vibration chamber. Another suggestion is that the stopper, which is short, light, and held in place by only the O-ring, vibrates with the air column of the flute."[42]

Flauti Briccialdi also shares some thoughts on why the Briccialdi Titanium Stopper is a stronger choice than traditional cork. Flauti Briccialdi's claims are based on Leslie Eggs's considerations as he created the O-Ring stopper: "According to Eggs [creator of the O-Ring stopper], getting the cork wet would damage the sound and timbre of the instrument, eliminating the vibrations in the walls of the headjoint. This theory is still valid and shared today."[43] When asked why their stoppers work, Flauti Briccialdi answers: "Perhaps the answer lies in the:

1. Greater space that exists inside the tube between the stopper and the crown
2. Freer vibrations: The headjoint is left to vibrate more freely with the air column because there is only a small amount of contact with the tube from the O-ring."

The plethora of commentary on the positive effects of non-cork stoppers come mainly from manufacturers and player testimonials. Without studies, tests, or data to support these marketing claims, it is perhaps unsurprising that many players still use the original cork stopper that came with their instrument.

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[42] Bigio, "Stoppers and Crowns."

[43] "Briccialdi Titanium Stopper Plug," Briccialdi Flutes Italy.

Research Available on the Stopper's Effects

In most general flute resources, the stopper is described as the primary tuning mechanism of the flute, as it can drastically affect the flute's overall intonation and balance between the three-octave range. Overall tuning on the flute is achieved by adjusting the length of the tubing, or the specific position of the stopper compared to the center of the embouchure hole. The stopper and its function regarding intonation is mentioned in leading flute resources, such as Nancy Toff's *The Flute Book* and *The Development of the Flute*.[44] It is also described in Phelan's *The Complete Guide to the Flute and Piccolo*, and Maclagen's *Dictionary for the Modern Flutist*.[45]

Some resources provide details on the negative effects of a cork that is out of alignment. The "McGee Flutes" webpage includes helpful general information on the effects on intonation if the stopper is in the wrong location,[46] and Paul A. Dickens goes into even greater detail about the same effects in his dissertation, *Flute Acoustics: Measurement, Modeling, and Design*.[47] He also includes the effects on an older flute design—an 8-keyed flute by Rudall & Rose. Furthermore, Wolfe, Smith, and Green found that the stopper's location also affects acoustic impedance (the

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[44] Nancy Toff, *The Flute Book: A Complete Guide for Students and Performers. 2nd ed.*; Nancy Toff, *The Development of the Modern Flute, 1st ed.* (Champaign, IL: University of Illinios, 1986).
[45] James Phelan, *The Complete Guide to the Flute and Piccolo. 2nd ed.* (Acton, MA: Burkart-Phelan, 2000); Susan Maclagen, *Dictionary for the Modern Flutist* (Lanham, MD: Scarecrow, 2009).
[46] "Effect of Stopper Position," McGee Flutes, accessed March 24, 2020, http://www.mcgee-flutes.com/Stopper.html.
[47] Paul A. Dickens, "Flute Acoustics: Measurement, Modelling, and Design" (PhD diss., University of New South Wales, 2007).

ratio of acoustic pressure to volume flow), but none of these resources discuss the effects of stopper beyond intonation.[48]

Documented Experiments on Flute Stoppers

Three previous experiments explore the acoustic and perceptual effects of stoppers in modern C flutes: (1) Stopper maker David Symington in the United Kingdom conducted a perception test on his stoppers made of many different metals; (2) Canadian Jasmine Tait conducted an experiment that compared the acoustic effects of the cork stopper to the Bigio stopper; and (3) Péter Rucz conducted an acoustic analysis of novel flute stopper designs from Hungary. These experiments are described in more detail below.

Perception Tests

Amateur flutist and stopper maker David Symington conducted perception tests on stoppers he made from different metals. His experiment tested stoppers of 16 materials with an identical design, and he published his detailed, personal perceptions as a player in the British Flute Society's journal, *Pan: The Flute Magazine*. Specifically, he used Bigio's stopper design, but included other metals and alloys that Bigio did not offer.

Symington stated that, "each metal seems to be distinctive—varying in responsiveness, power, resonance, and other tonal qualities difficult to describe."[49] More specifically, Symington said he felt (as a player) that metals produced a "more

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[48] Joel Wolfe, John Smith, and Michael Green, "The Effects of the Placement of the Head Joint Stopper on the Impedance Spectra of Transverse Flutes" (Conference Paper presented at the Eighth Western Pacific Acoustics Conference, Melbourne, Australia, April 7-9, 2003). Accessed on March 24, 2020, https://newt.phys.unsw.edu.au/jw/reprints/stoppers.pdf.
[49] David Symington, "Stopper Sounds."

robust and direct tone" than Delrin, which seemed more delicate. Figure 20 provides a summary of his perception results.

Figure 20. Symington's Perception Test Results[50]

Stopper Material and Density	Weight (when noted)	Perceptual Effects
Aluminum (2.7g/cm^3)	3.4g	Wild and unfocused.
Aluminum (2.7g/cm^3)	6.3g	Improved: light and airy tone.[51]
Titanium (4.51/cm^3)	9.7g	Somewhat like aluminum, but strikingly resonant and with a better, centered sound.[52]
Zirconium (6.49/cm^3)	14.7g	Clear, bell-like and very resonant throughout.
Tin 96.5%/Copper 3.5% (7.35/cm^3)	N/A	Uninteresting. Tone inflexible and lacking resonance.
Brass (8.55/cm^3)	N/A	Unremarkable.
Copper (8.96/cm^3)	N/A	Bright and resonant. Brassy sounds – Reminiscent of a cornet or trumpet.
Sterling Silver (10.38/cm^3)	N/A	Similar to copper, but slightly huskier and less responsive. Lacks copper's "brassy" quality.
Lead (11.84/cm^3)	N/A	Surprising and unusual tone. No homogeneity between the octaves. Quite resistant and the tone is inflexible.
Hafnium (13.1/cm^3)	21.1g	Similar to but darker in sound than zirconium.[53]
Tantalum (16.1/cm^3)	27.4g	Somewhat similar to Hafnium, but more resistant. Might suit a player who likes a dark tone.
Gold 22k (18.56/cm^3)	28.1g	Gives a very beautiful, rich low octave but is otherwise rather stiff/inflexible.
Tungsten (19.1/cm^3)	29.7g	Powerful and responsive, but with an arid, empty tone
Tungsten 75%/Copper 25% (14.8/cm^3)	23.7g	Great improvement over tungsten. Good response, robust sound with a touch of "brassiness" because of copper

[50] David Symington, "Stopper Sounds," 16-17.
[51] Symington found that 6.3g of Aluminum produced better results than 3.4g.
[52] Symington found that 9.7g of Titanium produced better results than 7.1g.
[53] Symington found that 29.6g of Hafnium produced better results than 21.1g.

Even though Symington conducted perception tests only on himself as a player, his experiment was significant because he included detailed descriptions of the weights, densities, and perceptual effects of the desirable and less appealing stopper materials.

Furthermore, he also examined the effects of weight, while keeping the material and design constant. He tested the effects of weight on seven of his zirconium stoppers that weighed 5.8 to 18.3g. He found that 5.8g gave a "poor, shallow sound with a weak low register." Increasing the weight to 14.7g and 15.6g produced a "clear, reasonably powerful and well-balanced tone" that was consistent throughout the registers. Increasing the weight to 17.1g and 18.3g added resistance that gave the low register more power, but muffled and limited the flexibility of the other registers.[54]

From these results, he postulated three useful theories:

1. Each stopper material has an optimum weight.
2. The optimum weight can vary from headjoint to headjoint.
3. The optimum weight correlates with the density. The greater the density, the greater the optimum weight. (i.e. A higher density with lower weight would be less optimum.)

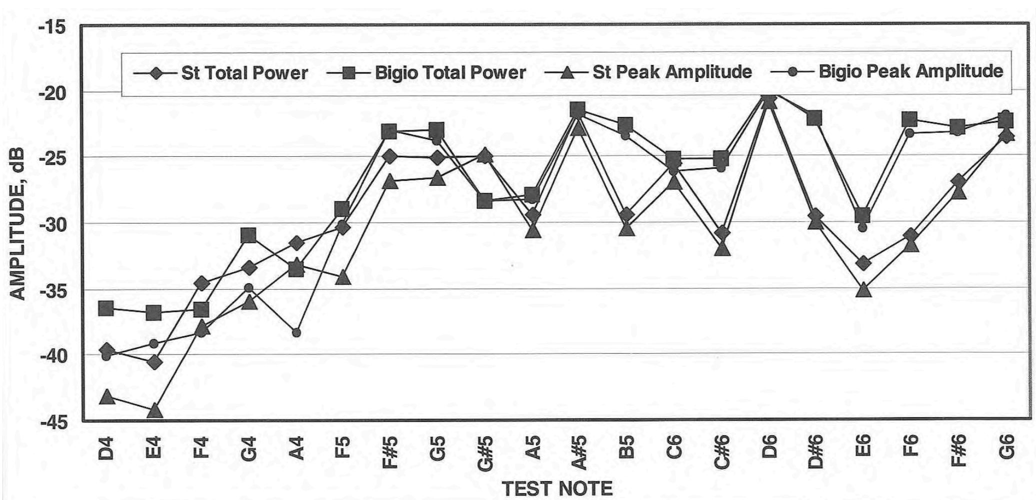
These results illustrate how difficult it is to isolate variables in stopper experiments, but may also assist in creating effective and desirable stoppers in the future.

[54] David Symington, "Stopper Sounds."

Acoustic Experiments

The second stopper experiment article was published in the *Canadian Acoustics* journal in 2001. High school student Jasmine Tait compared the loudness and harmonic brightness of a standard cork stopper with Robert Bigio's Stopper and Crown.[55] In her experiment, she recorded many different pitches and analyzed the harmonic strength with SpectraPro software. She graphed the loudness (power) and the strength of the harmonics above the fundamental (amplitude in dB) of both stoppers (see Figure 21).

Figure 21. Tait's Test Results (Bigio Crown and Cork Stoppers)



Tait found that Bigio's stopper produced a louder volume and stronger harmonic content overall, and that the greatest variation between the stoppers occurred in the upper register above A-sharp5. She also included a very interesting

[55] Jasmine Tait, "A Comparison of Acoustic Effects of Two Stopper and Crown Systems in the Modern Flute," *Canadian Acoustics* 29, no. 4 (December 2001): 40-44, accessed March 24, 2020, http://jcaa.caa-aca.ca/index.php/jcaa/article/viewFile/1421/1165.

suggestion for further development that would make it easier to determine the effects of the stopper: "I would like to see this type of stopper modified to become a digital sensor that could automatically vibrate in sympathy with the frequencies of each note. This could be applied to new digital flute technology."[56]

The third experiment, also acoustically based, was conducted on two new flute stopper designs of differing materials created by Zoltán Lakat (see Figure 22).[57] In Péter Rucz's experiment, he tested five stoppers' loudness, spectral centroid (the "center of gravity" of the harmonics present in the tone), and the "attack phase," otherwise known as the response or length of the transient (defined in the footnotes below).[58] The two stoppers with novel design #1 were made of cocobolo wood and cattle calf bone, and the three stoppers with novel design #2 were made of steel, silver, and titanium.

Using acoustic analysis, Rucz found that the stoppers affected dynamics with "remarkable" differences between the spectral envelopes produced by the different materials. For example, he found that the steel stopper produced a louder dynamic in the middle and upper registers of the flute compared with the traditional cork design. He also stated that the dynamic range of the silver and steel stoppers was slightly wider than cork, but the dynamic range of the bone stopper was narrower than that of cork. With a spectral analysis of the stoppers, he found that the spectral

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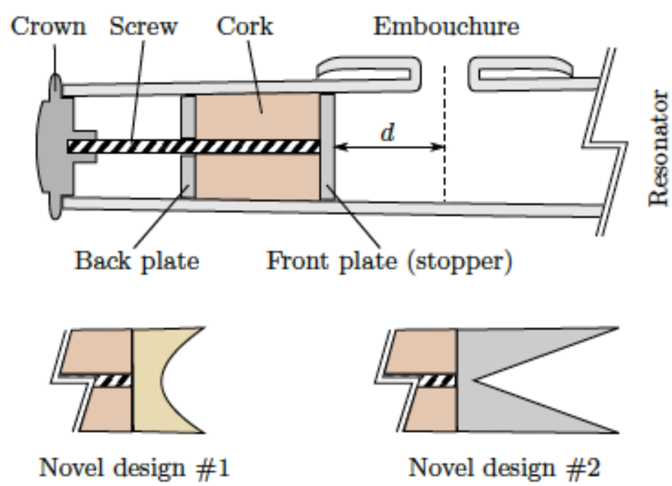
[56] Jasmine Tait, "A Comparison of Acoustic Effects of Two Stopper and Crown Systems in the Modern Flute."
[57] Péter Rucz, "Acoustical Evaluation of a Novel Flute Head Construction Acoustical Evaluation of a Novel Flute Head Construction" (Conference Paper presented at the 44th German Annual Conference on Acoustics, München, Germany, March 19-22, 2018).
[58] A transient is a high amplitude, short-duration sound that occurs at the beginning of a waveform.

centroid was higher for the steel, cocobolo, and titanium stoppers than that of bone and cork, especially in the lower register.

Rucz's findings about these unique stopper designs were certainly interesting, producing results similar to earlier experiments. His findings specifically confirm that the stoppers can create inconsistencies in loudness and spectral centroid that vary depending on the register. Unfortunately, in Rucz's experiment, it was difficult to determine if the effects were caused by the stoppers' novel designs or the materials themselves.

Figure 22. Two Novel C.E. Stopper Designs by Lakat[59]



<u>Online Stopper Resources</u>

An exhaustive literature search found that Symington, Tait, and Rucz appear to be the only people who have published results of their stopper experiments. Less reliable sources of useful, relevant information on the stopper include YouTube

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[59] Péter Rucz, "Acoustical Evaluation of a Novel Flute Head Construction Acoustical Evaluation of a Novel Flute Head Construction."

videos, online podcasts, and webpages. For example, Jennifer Cluff (former principal flutist of The Vancouver Island Symphony) interviews Raymond Robinson (a flute hobbyist) about his research comparing traditional cork stoppers with various Bigio and Dyna Flute System Stoppers in her educational Flute Loops podcast.[60] Robinson's playing test audio files and Cluff's interview are openly accessible via her website. These recordings played a large part in why I chose to research flute stoppers, due to audible differences in tone quality and color perception.

YouTube also currently contains a few useful videos on flute stopper installation. Roberto Feliciano, creator of the Celestine Rexonator, posts videos to communicate directly to his customer base on his channel, "RFrolon." In his videos, Feliciano gives detailed instructions on how to remove the cork from the headjoint, how to install his stopper, and how to customize the colored O-rings and brass rings to fit personal preference.[61] The other installation video currently on YouTube is by Paul Leithold, of Leithold Music, regarding the Performance Flute Plug (a non-cork stopper made of Delrin).[62]

With the many questions flutists have about flute gadgets and upgrades, I was expecting to find more video reviews on YouTube. However, very few are available, and only one worth mentioning. Amelie Brodeur of "The Flute Channel"

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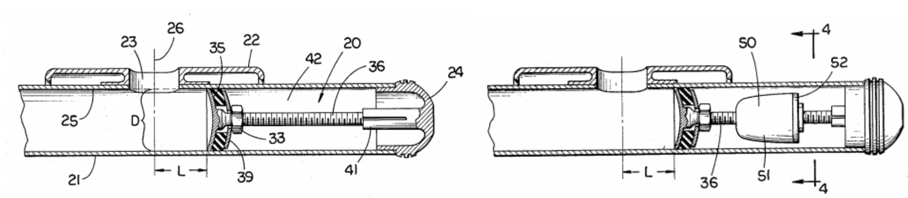
[60] Jennifer Cluff, "Raymond Robinson Tests Flute Crowns and Stoppers by Robert Bigio and DynaSystems," sound file, Flute Loops 8 (2007), accessed March 24, 2020, https://www.jennifercluff.com/fluteloops08.htm.
[61] Roberto Feliciano, "RFRolon," YouTube Channel, founded on November 28, 2007, and accessed March 24, 2020, https://www.youtube.com/user/rfrolon.
[62] Paul Leithold, "Performance Flute Plug Installation Guide," YouTube video, posted on January 14, 2015, and accessed March 24, 2020, https://www.youtube.com/watch?v=NkKfR8B5T28.

created a video featuring Peter Robinson and his Swap-Stopper.[63] The remaining stopper-related videos on YouTube are the Celestine Rexonator player testimonials that are published on Feliciano's website.

Patents

If stopper makers wish to protect their intellectual property, they file a patent to protect their unique designs. Each of these patents include valuable stopper information, such as a summary of the invention, a detailed description and labeled figures of the invention's components, the invention's claims (the design details of which the inventor is claiming possession), and background information on the invention. The patents can also include other proposed variations of the invention, such as the two stopper designs James Pellerite included in his patent (see Figure 23).[64] It should be noted that the invention's "claims" section is where the filer provides the specific details of the unique design or intellectual property, not the invention's claimed effects.

Figure 23. Two Proposed Stopper Designs in Pellerite's U.S. Patent



63 Amelie Brodeur, "Flutealot's Swap Stopper System Kit," YouTube video, posted on February 21, 2018, accessed March 24, 2020, https://www.youtube.com/watch?v=tEeebmOA2ZQ.
64 James Pellerite, Headjoint Stopper.

Notable U.S. stopper patents (some of which have been discussed previously) include: Pellerite's "Headjoint Stopper" (1980) called the O-Ring;[65] Ferron's "Obturator for flute designed to improve the emission of certain notes" (1983), which became the Logicork;[66] Seidman's "Acoustically Pleasing Headjoint Stopper for a Transverse Flute" (2008), which became the Seidman Flute Stopper Plug;[67] Gary Lewis' "Headjoint Crown Assembly with Extension Unit" (2014), which became the Gary Lewis Select Crown Assembly;[68] and Feliciano's "Rhino Resonator and Flute Crown" (2018), which became the Celestine Rexonator.[69] Outside the U.S., notable patents include Peter Robertson's "Variable Flute Stopper" (2015), which became the Swap-Stopper.[70] Unexpectedly, a patent for Bigio's Stopper and Crown does not exist. This lack of a patent allowed Symington to use Bigio's design to create his stoppers from many different alloys (such as Symington's Flutemet).

<u>Relevant Non-Stopper Flute Experiments</u>

Although very few experiments conducted on stoppers exist, acoustic and perception-based experiments on crowns and headjoints are worth noting because they tested similar variables or effects. These experiments include acoustic analysis and perception-based tests on flutes made of varying materials. In particular, the

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[65] James Pellerite, Headjoint Stopper.
[66] Ernest Ferron, Obturator for Flute Designed to Improve the Emission of Certain Notes.
[67] Mark Seidman, Acoustically Pleasing Headjoint Stopper for a Transverse Flute, US Patent US2010/0018380A1, filed July 23, 2008, application published January 28, 2010, and application abandoned, accessed on March 24, 2020, http://www.seidmanflutetechnology.com/acoustic-qualities.html.
[68] Gary Wayne Lewis, Headjoint Crown Assembly with Extension Unit.
[69] Roberto Feliciano, Rhino Flute Resonator and Crown.
[70] Peter Robertson, Variable Flute Stopper, United Kingdom Patent GB2544047A, filed November 2, 2015, application published May 10, 2017, and application pending.

effect material has on tone quality, tone color, and response is the subject of a long-running disagreement between musicians, instrument makers, and physicists.[71] Experiments on flute material by John Backus and John Coltman in the mid-twentieth century paved the way for the more detailed and sophisticated experiments we can conduct today.

John Backus's experiment on the effect of material in woodwind instruments in the 1960s is frequently referenced in current articles published on instrument material. It is also an important acoustic-based test on flute wall material. Backus sought to determine if the differing vibrations of the wall material would affect tone quality by "radiating sound themselves or altering the form of the internal air-column vibration."[72] Ultimately, he found no evidence that wall material has a notable effect. This experiment is not generally accepted by flutists and instrument-makers, however, because the instruments were artificially blown by a machine, not a human.[73]

A second well-known experiment can be found in Coltman's article, *Effect of Material on Flute Tone Quality*, published in *The Journal of the Acoustical Society of America* in 1971.[74] In his experiments, Coltman conducted two perception-based

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71 Renate Linortner, "Silver, Gold, and Platinum: Wall Material and the Sound of the Flute," excerpt (PhD diss., University of Music and Performing Arts Vienna, Institute of Music Acoustics, 2001), accessed on March 24, 2020, http://iwk.mdw.ac.at/?page_id=97&sprache=2.
72 John Backus, "Effect of Wall Material on the Steady-State Tone Quality of Woodwind Instruments," *The Journal of the Acoustical Society of America* 36, no. 10 (October 1964): 1881-1887, accessed on March 24, 2020, https://doi.org/10.1121/1.1919286.
73 Renate Linortner, "Silver, Gold, and Platinum: Wall Material and the Sound of the Flute."
74 John W. Coltman, "Effect of Material on Flute Tone Quality," *The Journal of the Acoustical Society of America* 49, no. 2 (1971): 520-523, accessed on March 24, 2020, https://doi.org/10.1121/1.1912381.

experiments using three wall materials, first on a group of 27 listeners and then on four players. He hoped to determine if the listeners and players could correctly identify the material in use. He found that neither experienced listeners nor trained players could correctly identify the tubing material. These findings are significant and relevant to stoppers, because they indicate it is possible that material does not play a role in the stopper's effects, as well.

Joan White's 1980 dissertation called *A Spectral Analysis of the Tones of Five Flutes Constructed of Different Materials* examines the acoustic effect of the flute's wall material.[75] She included five identical modern Boehm system flutes made of white gold, 14-karat gold, palladium, and two made of sterling silver. The playing tests were conducted in an anechoic chamber and included sustained tones from three registers. Each frequency was performed without vibrato and at two dynamic levels: *piano* and *forte*.

White explored the influence of wall material, intensity level, and frequency. Perhaps more significantly, she also explored the influence of the performer on the harmonic content (otherwise known as timbre or brightness) on each flute in the experiment. The spectral analysis was completed with real-time analyzer called Spectral Dynamics, model SD330A. Her findings were intriguing. Most notably, she found that:

1. The material of the five flutes produced a significant difference for partials 1, 2, and 4, but the interaction between the player and the flute was significant for partials 1 and 3.

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[75] Joan White, "A Spectral Analysis of the Tones of Five Flutes Constructed of Different Materials" (Ed.D diss., The University of North Carolina at Greensboro, 1980), accessed on March 24, 2020, http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/303037716?accountid=4485.

2. The material affected the intensity (loudness) of all partials, but the player greatly affected the strength of partial 1.
3. The variation difference between the players is the greatest in partials 1, 3, and 4.
4. The second partial seems to be the least affected by the wall material or the performer.

White's dissertation identifies how and when the player most strongly affects the intensity, brightness, and frequency, and when it may be affected by the wall material. Her results are useful because it is difficult to separate the effects of the player from the effects of the instrument, which is a concern in all flute experiments that include live performers.

Another relevant experiment included an acoustic analysis and a perception-based test conducted on the effects of wall material by Linortner in 2001.[76] In these experiments, seven professional players tested the effects of various silver, gold, and platinum flutes in an anechoic chamber. Specifically, Linortner included flutes that were silver-plated, all silver, 9-karat gold, 14-karat gold, 24-karat gold, platinum-plated, and all platinum. After recording the playing test, he analyzed the sound which was later turned into a listening test that included 15 experienced professional flutists as subjects. Additionally, Linortner conducted an opinion survey on the relationship between wall material and tone color and response with 111 persons.

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[76] Linortner, Renate, "Silver, Gold, and Platinum: Wall Material and the Sound of the Flute," Thesis excerpt (PhD diss., University of Music and Performing Arts Vienna, Institute of Music Acoustics, 2001), accessed on March 24, 2020, http://iwk.mdw.ac.at/?page_id=97&sprache=2.

In Linortner's sound analysis, he found the greatest acoustic differences in tone color and dynamics were due to the variations among players, not variations in wall material. He also found that the difference between the material with the smallest dynamic range (24-karat gold) and the material with the greatest dynamic range (all platinum) was only 1.5 decibels (dB).[77] The two listening tests had similar results: no instrument material was correctly identified above chance level, and the identification data was best described as "contradictory." This meant that listeners simultaneously described the sound as "bright" and "dark," or "full/round" and "thin/sharp."

A similar experiment was conducted by Corinth Young in 2009 on the effects of wall material and manufacturer.[78] Young tested 75 flutes made of gold and silver by Brannen Brothers Flute Makers Incorporated, Verne Q. Powell Flutes Incorporated, Burkart-Phelan Incorporated, and Wm. S. Haynes Flute Company. Young found that there is a possible correlation between material and timbre, especially in the strength of partials 1 and 3. She also found that the manufacturer had an effect on the measured intensity of harmonics in the sound. In particular, Brannen had stronger lower harmonics (1-4) and Powell had weaker harmonic intensity for higher partials (6-9).

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[77] Linortner notes that this variation could become zero with more playing tests.

[78] Corinth D. Young and Diane Boyd Schultz, "Effects of Head Joint Material and Instrument Manufacturer on Flute Timbre, as Measured by the Intensity of the First Nine Overtones in the Harmonic Series," *The University of Alabama McNair Journal,* 139-154, accessed on March 24, 2020, http://www.shmuelyosef.com/Saxophones/Flute/Articles/Effects%20of%20Head%20Joint%20Material%20and%20Instrument%20Manufacturer%20on%20Flute%20Timbre.pdf.

The last relevant experiment tested the effects of crown material. Yamauchi, Kai, and Iwamiya conducted a blind perception-based test on crowns made of aluminum, brass, copper, iron, and tungsten.[79] The single-blind perception test asked listeners to rate the quality of the tone on 13-step scales. These Likert-type scales included: thick-thin; powerful-powerless; rich-poor; ringing-damped; tight-loose; deep-metallic; beautiful-dirty; rough-smooth; soft-hard; calm-shrill; bright-dark; sharp-dull; and distinct-vague. These 13 categories were then organized into three sub-categories: potency and beauty, clearness, and brightness. The study found that the copper and tungsten crowns were clearer and brighter (ideal tone and stronger higher harmonics present in the sound), the aluminum was muddier (less focused), and the brass was darker (fewer higher harmonics in the sound).

Remaining Questions

Even with the existing literature available and experiments conducted on stoppers, many questions about the effect of the material and design still remain unanswered. Based on the related acoustic and perception-based experiments on wall and crown material, flutists would benefit from having access to research that examines both acoustic analysis and perception-based studies of the available stoppers. Although many of the products available showcase enthusiastic player testimonials, it would be helpful if the makers' claims were based on more than testimonials and non-blind perception tests that can be subject to unintentional bias.

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[79] Katsuya Yamauchi, Yasunao Kai, and Shin-ichiro Iwamiya, "The Effects of Materials of a Flute's Crown and a Cello's Endpin on the Timbre of Musical Instruments," *Acoustical Science and Technology* 22, no. 1 (2001): 47-48, accessed on March 24, 2020, https://doi.org/10.1250/ast.22.47.

Many flutists are hesitant to switch to a new kind of stopper, so clear findings on the effects could help flutists overcome this obstacle.

Currently, the established findings are mostly limited to stopper makers and amateur flutists interested in flute acoustics who discuss only a small sample of the stoppers available. Perhaps with more published research available, the stopper will earn more attention and consideration when flutists tailor their flutes to fit their personal preference.

CHAPTER 4

STOPPER USAGE TODAY: A SURVEY

The key question on stopper usage today is: What do flutists think about non-cork stoppers and are they widely used? Visually, it is hard to know when someone is using a cork or non-cork stopper because stoppers are completely hidden from view within the tubing. To gather information on current stopper usage, I asked flutists over the age of 18 to complete a short survey that was shared online, on social media, and via email. I asked questions about which stoppers student, amateur, hobbyist, and professional flutists currently use; which stoppers have they used in the past; and what they like or dislike about the stoppers they have tried. The questions were designed to answer four questions:

1) Do people know about non-cork stoppers?
2) Who is playing with non-cork stoppers and which ones?
3) What specifically do flutists like and dislike about non-cork stoppers?
4) If there were published studies on the effects of stoppers, would cork stopper players be willing to try non-cork stoppers?

Among the different outlets the survey was shared, a total of 175 responses were received.[80]

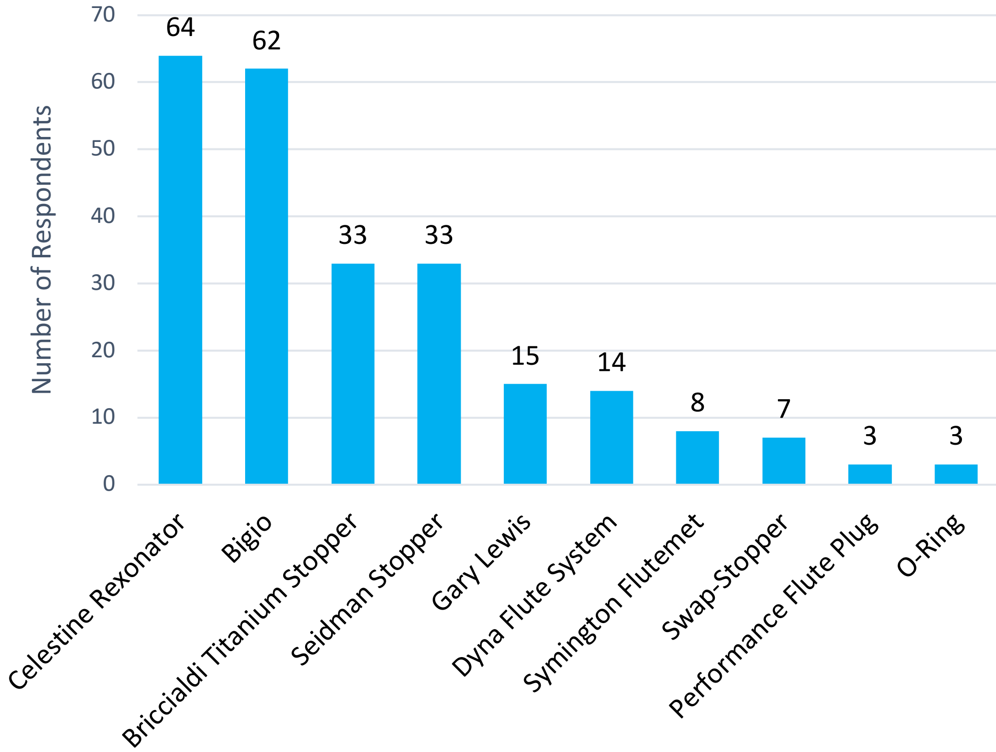
[80] Flutists were invited to participate in the Qualtrics survey via email and Facebook. They were also invited to share the survey link. No incentive was offered.

Stopper Awareness

To answer the first question and discover if and how much flutists know about the specific kinds of non-cork stoppers available today, I included in the survey a list of the stoppers that seemed to be the most used and had the most information available online: Bigio Stopper, Briccialdi Titanium Stopper Plug, Celestine Rexonator (previously known as the Rhino Resonator), Dyna Flute System, Gary Lewis Select Crown Assembly, Seidman Flute Stopper Plug, Swap-Stopper, and Symington Flutemet. I asked each respondent to check the box of each stopper about which they had heard. I also included the option to write in the name of other stoppers they were familiar with that were not included on the list. A few flutists were familiar with the Performance Flute Plug by Bob Ogren and Pellerite's O-Ring.

Considering that the vast majority of flutists use cork stoppers, the results were surprising. More than half of the respondents stated that they had heard of at least one kind of non-cork stopper. Specifically, 57% (101 flutists) knew of at least one kind of non-cork stopper, and 43% (75 flutists) did not know about any of the non-cork stoppers available. The Celestine Rexonator and Bigio stopper were the most-recognized among flutists who knew of at least one brand of non-cork stopper (see Figure 24).

Figure 24. Stopper Awareness



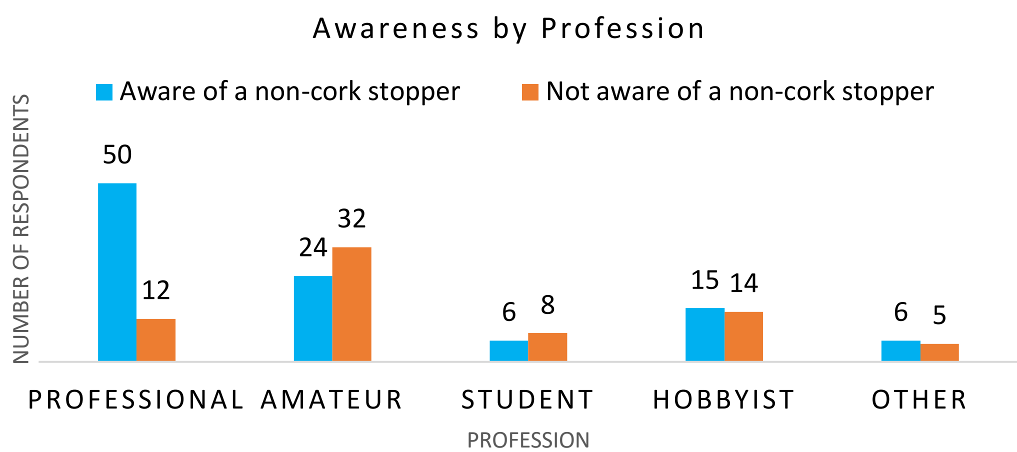
Since I was also interested in which category or population of flutists had the greatest familiarity with non-cork stoppers, I included five representative categories: Professional, amateur, student, hobbyist, and other. These categories included specific descriptions to help respondents choose the category that best fit them:

- Professional Flutist: A flute-related job(s) is my primary source of income
- Amateur: I studied music in college, but a non-flute job is my primary source of income
- Student: I am currently pursuing a flute-related degree in college
- Hobbyist: I play the flute as a hobby (I have never studied flute in college, and a non-flute job is my primary source of income)

- Other: Please describe

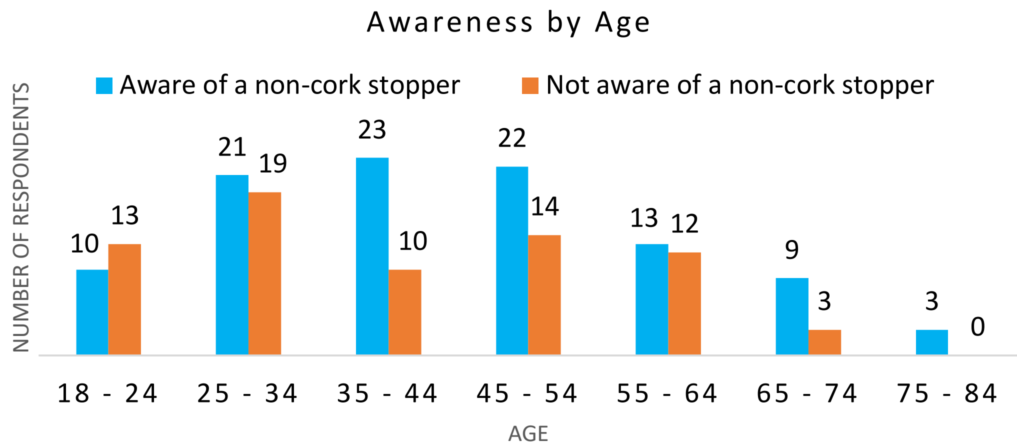
More than half of the respondents in three of the five categories were aware of at least one non-cork stopper: Professionals, Hobbyists, and Other (see Figure 25). The highest percentage of awareness included Professionals (81%), followed by Other (55%), which included flutists who were retired, repair technicians, and woodwind doublers whose primary instrument was not flute. A majority of hobbyists, 52%, were also aware of non-cork stoppers. Of the Amateur and Student populations, slightly less than half of flutists were aware of at least one non-cork stopper.

Figure 25. Populations Aware of at Least One Non-Cork Stopper



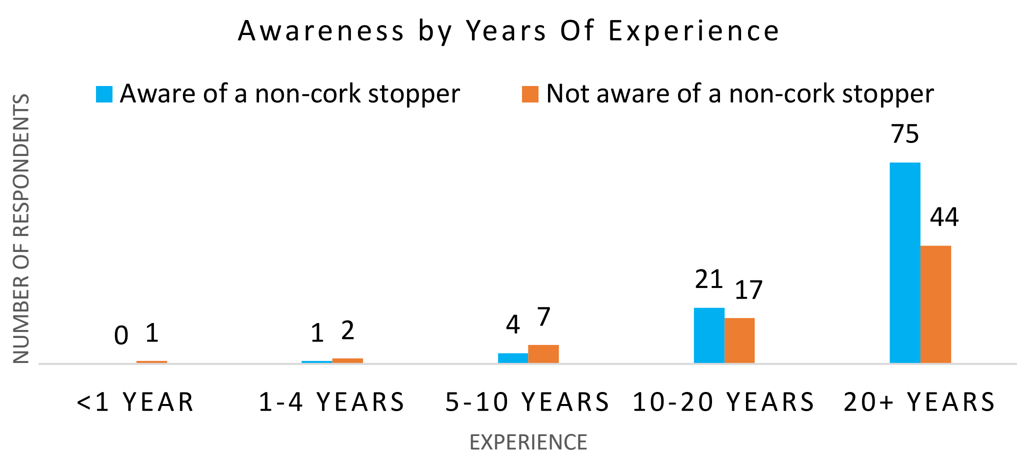
Based on the survey's request for age range, age did not seem to play a role in stopper awareness. I asked respondents to choose the age bracket to which they belonged, including: 18-24; 25-34; 35-44; 45-54; 55-64; 65-74; and 75-84. In all of the age brackets, more than half of the respondents were aware of at least one non-cork stopper, except ages 18-24 (see Figure 26).

Figure 26. Age Brackets Aware of at Least One Non-Cork Stopper



Lastly, the survey showed that years of flute playing seemed to coincide with stopper awareness. Of the five categories of years spent playing (Less than 1 year, 1-4 years, 5-10 years, 10-20 years, and 20+ years), flutists who had spent 20 or more years playing the flute had the greatest awareness of non-cork stoppers, by a significant margin (see Figure 27).

Figure 27. Experience Categories Aware of at Least One Non-Cork Stopper

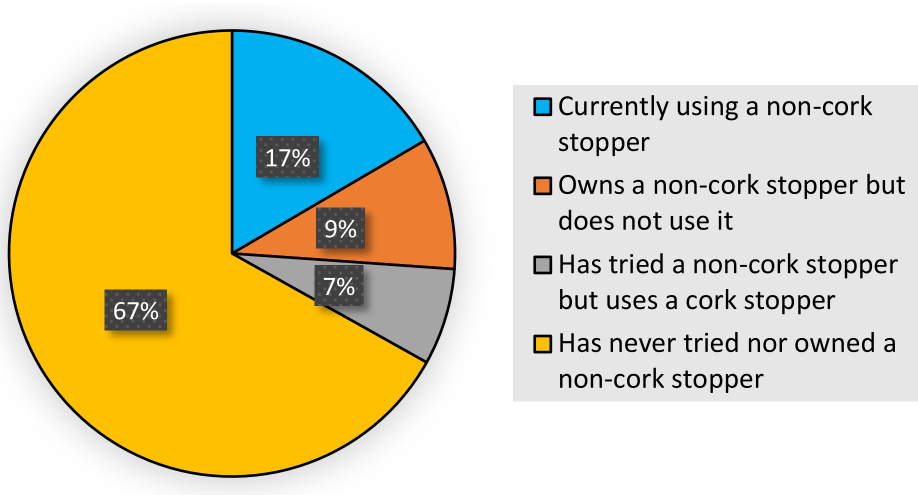


Cork vs. Non-Cork Stopper Usage

Once awareness was determined, the second question to answer included who is *playing* on non-cork stoppers. When asked which kind of stoppers they are currently playing (cork or non-cork), the results were unsurprising: 84% of the responding flutists were currently using a cork stopper, and a much smaller 16% were using a non-cork stopper.[81] To investigate this further, the survey also included questions about flutists' past experience with non-cork stoppers. Flutists were asked to answer if they fell into one of four categories: 1) Currently play on a non-cork stopper; 2) Own a non-cork stopper, but don't play it; 3) Play on a cork stopper, but have tried a non-cork stopper; and 4) Have never tried nor owned a non-cork stopper. This helped discover how many current cork users also own a non-cork stopper, and how many have tried one. A significant majority of the population included flutists who have never tried nor owned a non-cork stopper (see Figure 28). A small percentage of respondents currently own a non-cork stopper but do not use it or had tried a non-cork stopper, but have never owned one.

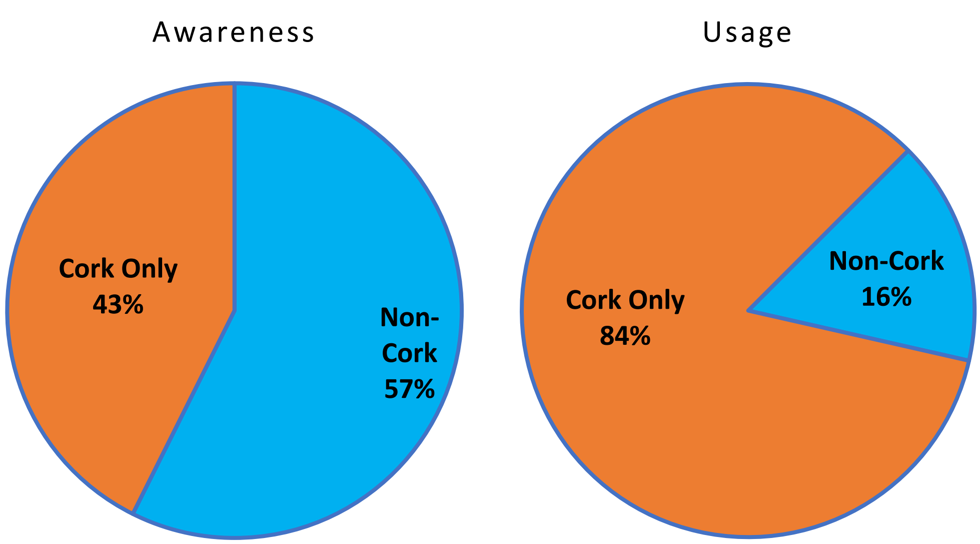
[81] 26 flutists are currently playing a non-cork stopper vs. 136 flutists currently using a cork stopper. 18 flutists did not respond to this question, either because they did not finish their survey, or because they were unaware of what kind of stopper was in their flute (not included in the data analysis).

Figure 28. Stopper Usage and Experience



These percentages clearly indicate that a strong majority of flutists are using cork stoppers, but it is also interesting to note that non-cork stopper usage varies significantly from awareness (see Figure 29). The percentage of flutists using non-cork stoppers is in inverse proportion to flutists' awareness of non-cork stoppers.

Figure 29. Stopper Awareness vs. Stopper Usage



It was interesting to see that the population groups most aware of non-cork stoppers were also currently *using* non-cork stoppers. The survey results showed that hobbyists (21%), professionals (18%), and amateurs (14%) had the greatest percentage of non-cork stopper usage (see Figure 30). Similarly, flutists with 10-20+ years of experience had the highest percentages of non-cork stopper usage (see Figure 31).

Figure 30. Stopper Usage by Population

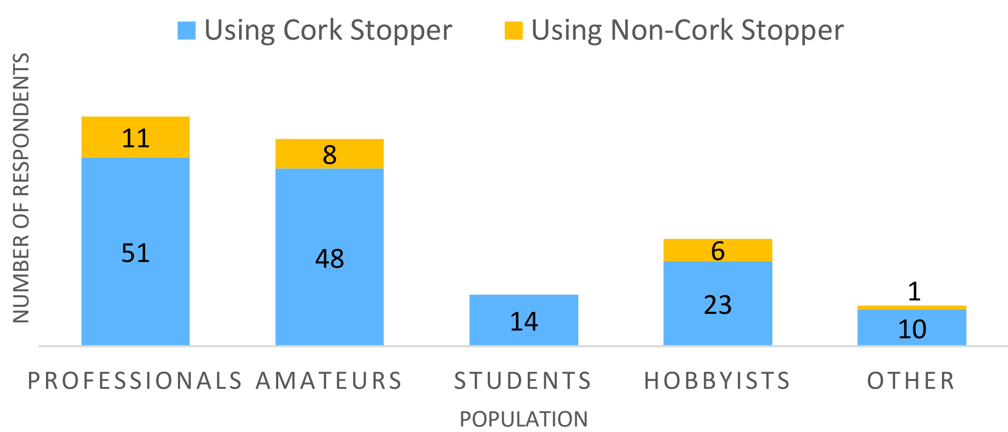
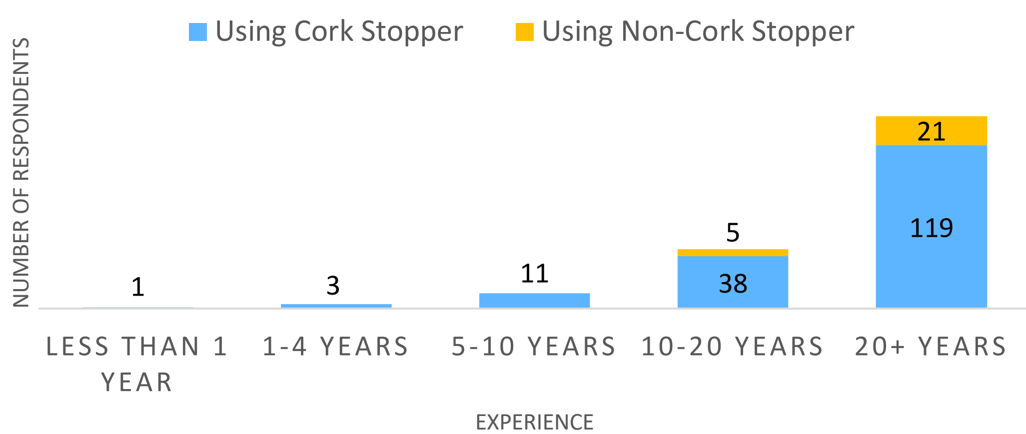
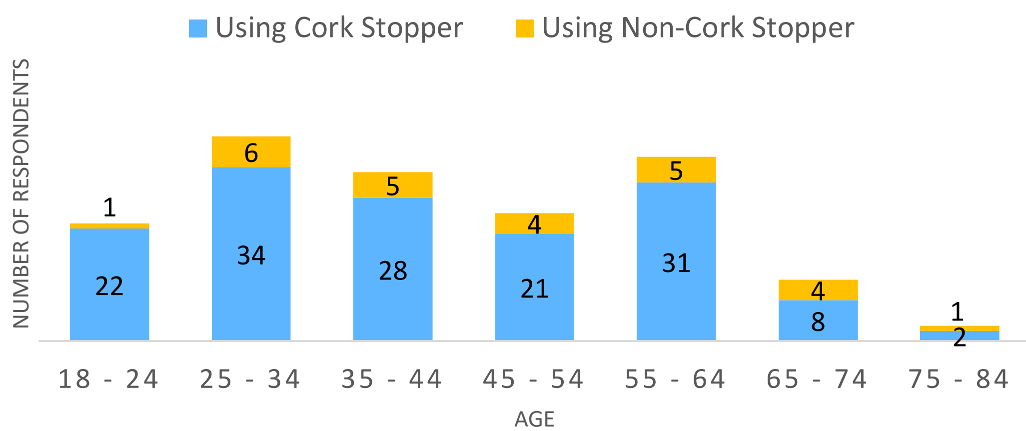


Figure 31. Stopper Usage by Total Years Playing Flute



Based on the survey, age did not seem to affect non-cork stopper usage significantly, with percentages very similar across four age brackets (see Figure 32). Approximately 14%-16% of ages 25-34, 35-44, 45-54, and 55-64 are currently using non-cork stoppers.

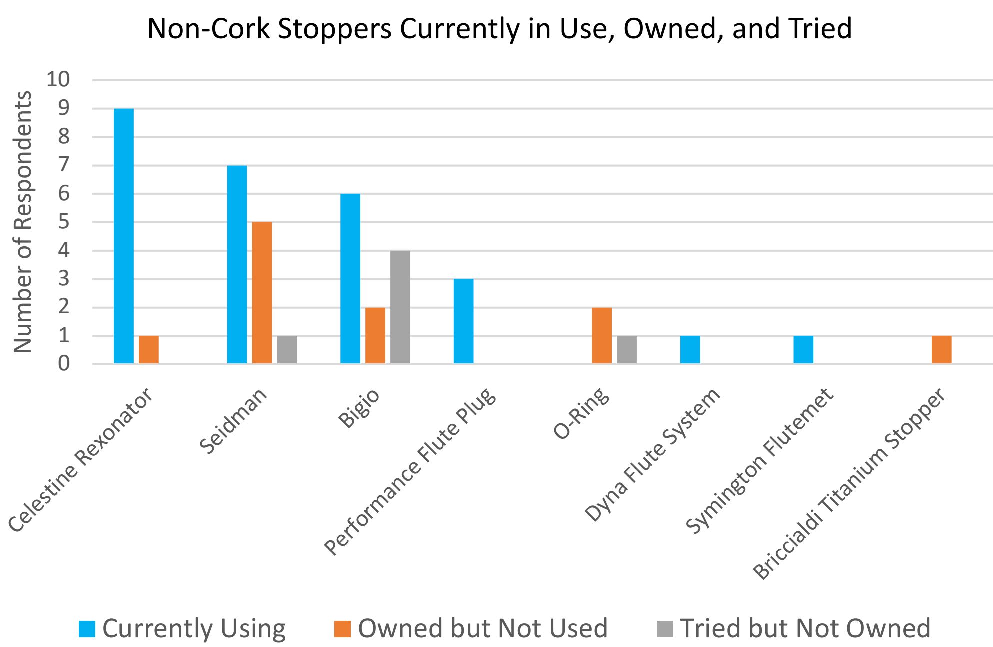
Figure 32. Stopper Usage by Age



Non-Cork Stoppers Currently in Use

Now that it was clear the types of flutists who were playing non-cork stoppers, it was important to uncover which non-cork stoppers players were using, and the stopper's effects on player perception. To do this, I looked at the non-cork stoppers respondents are currently using, have tried in the past, or own but do not use. Compared to the 175 flutists who submitted the survey, the number of flutists who are using, own, or have tried a non-cork stopper was much lower. However, of the 53 flutists with non-cork stopper experience, flutists surveyed were currently using the Celestine Rexonator (the most popular), closely followed by the Seidman and Bigio stoppers (see Figure 33). Eleven flutists owned a stopper but are not currently using it, and a few flutists had tried a non-cork stopper but had never owned one.

Figure 33. Non-Cork Stopper Usage



<u>Reported Non-Cork Stopper Perception</u>

The third question to answer was: "Which effects are flutists perceiving when using a non-cork stopper?" To investigate this, I asked respondents questions about their experience and perception. The participants were asked to rate how strongly they agreed with statements about their perception and choose from five Likert Scale responses: 1 being "Strongly Disagree" to 5 being "Strongly Agree." The survey questions can be found in Appendix A.

Overall, not many conclusions could be drawn from examining the effect of non-cork stoppers as a whole. Instead, I chose to look at the effects of specific individual non-cork stoppers that are available for purchase today. I limited the study to include the Seidman, Bigio, and Celestine Rexonator stoppers. The other stoppers had 0-3 total current and past players, so I chose to exclude them from this analysis.

Flutists currently using non-cork stoppers were much happier with the effects of the stopper overall than the flutists who had tried or were no longer using non-cork stoppers they own (see Figure 34). Because of this, I chose to examine the results separately from these two populations.

When looking at the perception results by stopper, the averages are similar to each other, which suggested little difference in perception. The greatest variation in the averages were for "focused tone," "ideal tone quality," and "ideal tone quality consistent throughout the registers," categories in which the averages varied by 0.8-0.89 points (nearly 1 whole point out of 5). The Bigio stopper performed the best in each of these categories, but the Seidman stopper performed slightly better in the "softer dynamic" category, and was also considered the brightest stopper. Unfortunately for the Celestine Rexonator, its averages were the lowest in all categories, except for brightness.[82] However, it is important to note that only 1 respondent had previously used a Celestine Rexonator, and they ranked each category at 1, so Celestine's results are not representative of a large population in the second chart in Figure 34.

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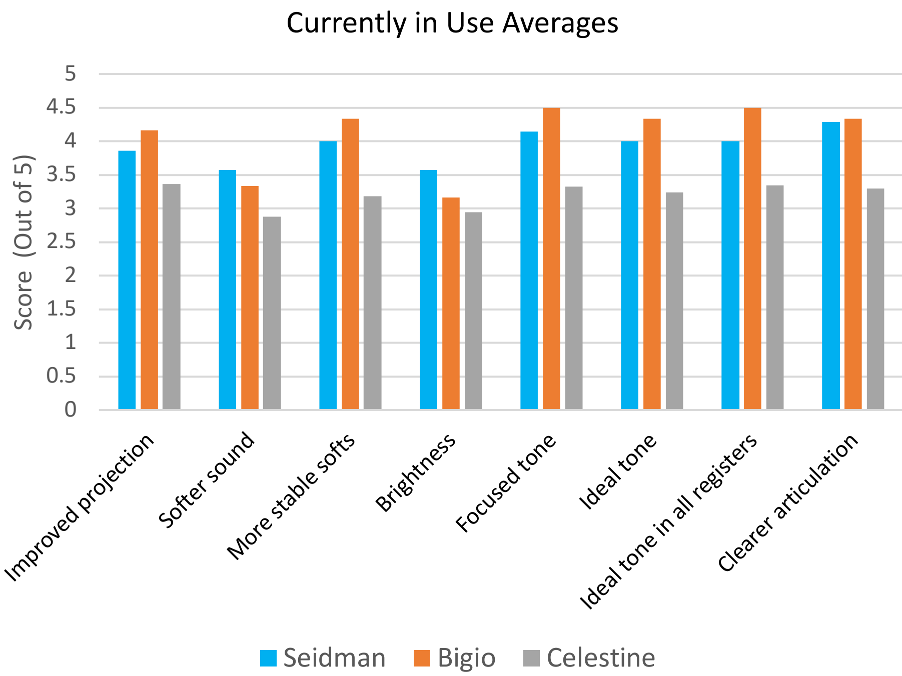
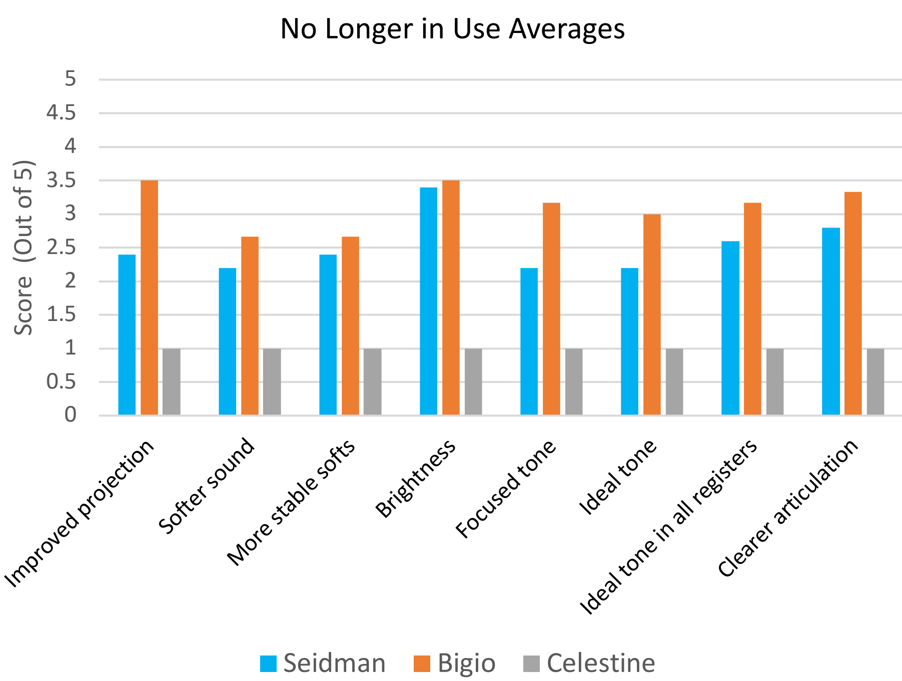
[82] Brightness preference tends to vary from player to player. A higher number correlates with a higher brightness.

Figure 34. Non-Cork Player Perception Results





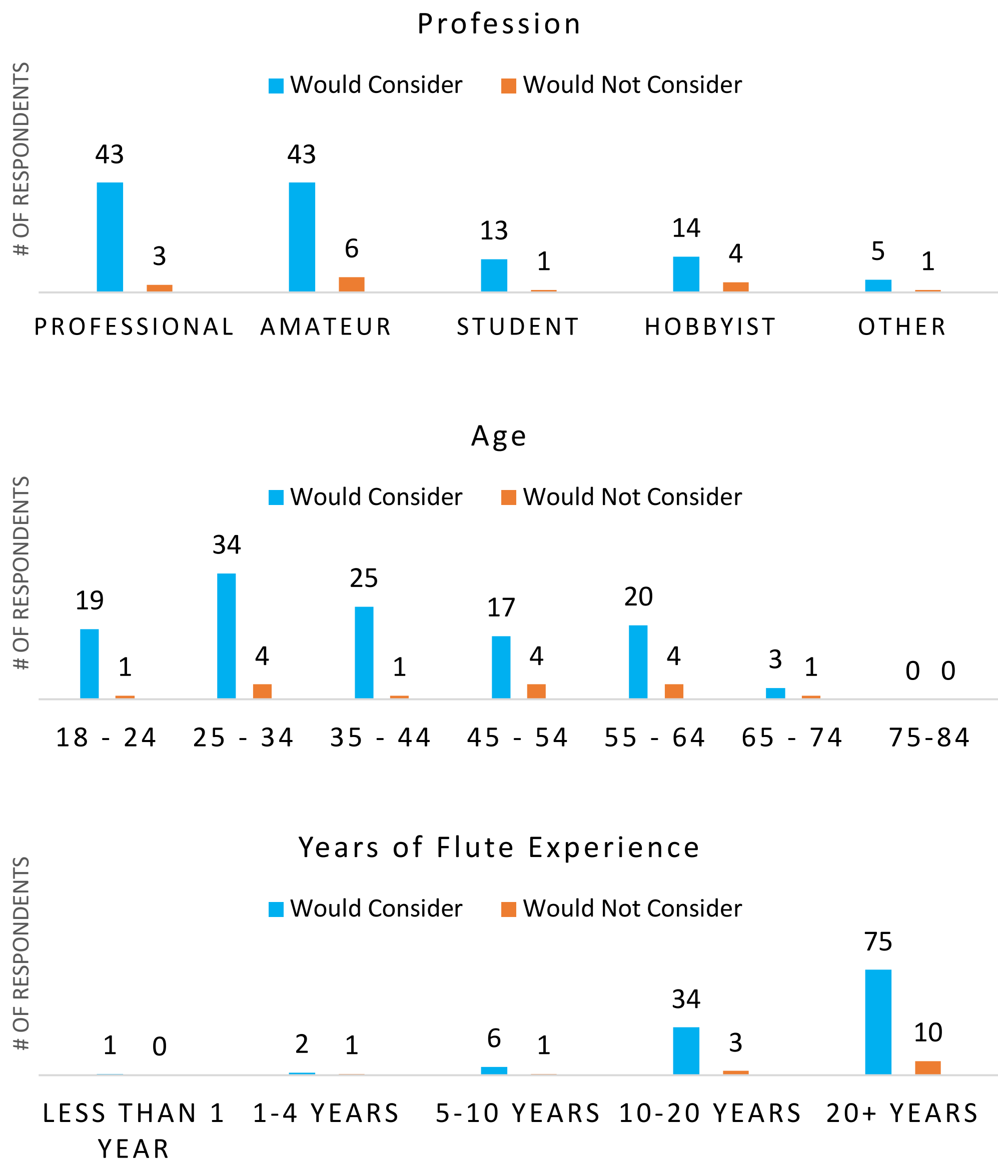
Effects of Published Studies on the Stopper's Effects

The fourth and final question to answer was if flute players using a cork stopper would be willing to consider a non-cork stopper if studies supporting its effects were published. Surprisingly, the survey found that 88% of respondents were willing to consider using non-cork stoppers with published studies. The remaining 12% (15 players) were unwilling to consider a non-cork stopper. I would like to note that the responses to this question may have been due to subject acquiescence response bias, where participants are more likely to agree with statements despite their content. This bias can be problematic in agree/disagree questions such as this survey question.[83]

Despite the potential bias, I thought it positive to see how open cork-playing flutists were to the idea of trying non-cork stoppers if studies were published on the effects. This openness was consistent across profession, age, and years of flute-playing experience (see Figure 35). A few people were unwilling to consider non-cork stoppers in each category (generally a small percentage with no perceivable influence).

[83] Allyson Holbrook, "Acquiescence Response Bias," in *Encyclopedia of Survey Research Methods*, edited by Paul A. Lavrakas (Thousand Oaks: SAGE Publishing, 2011), accessed on March 24, 2020. https://dx.doi.org/10.4135/9781412963947.n3.

Figure 35. Cork-Playing Groups Open to Considering Non-Cork Stoppers with Studies Available



<u>Further Questions about the Stopper's Effects</u>

In the final question of the survey, I asked flutists if they would like to include any comments. It was clear from these comments that many flutists were very curious about the effects of non-cork stoppers. Flutists remarked that they "did not know that non-cork stoppers existed," or "I am curious about" effects such as response, tone quality, perception, and other areas of performance. A couple of flutists stated that they did not have a stopper in the flute because they had never seen it. Clearly there is curiosity, but also room to improve general stopper knowledge.

Players who had previously used non-cork stoppers and found they had a negative effect or no effect at all said that stoppers had a minimal effect on the sound, that changing the headjoint was more effective, and the stopper's most important function was to seal the tube properly. This is unsurprising, because to date, little concrete evidence exists to prove the stopper's acoustic and perceptual effects. A majority of flutists who made these comments owned one non-cork stopper but no longer used it.

To find more definitive results and provide evidence of the stopper's acoustic and perceptual effects, I conducted single-blind experiments with more controlled variables that are discussed in the next chapter.

CHAPTER 5

EXPERIMENT DESIGN

Design Considerations

When I first became curious about the effect of stoppers, my initial goal was to determine the stopper's acoustic contributions to the sound; in other words, find an answer to the burning question, "What are these stoppers *doing* to the sound?" The long-running debate whether material affects or does not affect output and perception led me to conduct experiments to explore both the acoustic science and the human perception behind stopper usage. I conducted two types of single-blind experiments on five stoppers available today: (1) an acoustic analysis to determine the stoppers' acoustic effects; and (2) perception tests to examine how flutists perceive the effects of the test stoppers. The single-blind experiment method was chosen to minimize or eliminate bias from the players or listeners, since any bias could compromise the integrity and accuracy of the test results.

Acoustic output and perception are different yet equally important sides of the same coin. The acoustic experiment produced quantitative data on the acoustic output of the flute while using the different stoppers. Specifically, I measured the stoppers' dynamic capabilities (minimum to maximum loudness in dB), and its tone color or brightness (represented by spectral centroid, which has been proven to be the most accurate indicator of perceived brightness).[84]

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[84] Emery Schubert and Joe Wolfe, "Does Timbral Brightness Scale with Frequency and Spectral Centroid?," *Acta Acustica* 92, no. 5 (June 2006): 820-825, accessed on March 24, 2020, https://newt.phys.unsw.edu.au/~jw/reprints/SchubertWolfe06.pdf.

However, the conclusions drawn from the acoustic results alone are not very useful for performers for two reasons: (1) because perception is subjective and varies greatly, and (2) because players are perceiving changes in the sound and response that acoustic analysis cannot yet explain with the parameters previously investigated. The perception test was designed to explore the most important aspects of performance that flutists consider when choosing an instrument, and aid others in exploring these stoppers. It also investigated the perception stimuli that players and listeners experienced. The players experienced both tactile and aural stimuli, whereas the listeners would only perceive aural stimuli.

Ultimately, my hypothesis was that stoppers are affecting aspects of performance, and there may be possible correlations between the acoustic and perceived effects of the stoppers. Additionally, I attempted to determine if the makers' claims have any validity, because understanding and identifying possible effects of each stopper may assist flutists in purchasing a stopper that suits them best.

Playing Test

Stoppers Tested

When designing the experiments, I considered my research question ("What are the stoppers doing, acoustically and perceptually?"), the resources available, and the scope of research that was practically feasible. It was determined that testing the available stoppers of varying design and materials would be the most useful. This would make it more difficult to determine *why* the sound was affected (because it would be impossible to isolate the design and weight variables), but this question seemed a good one to address in the future, after this initial exploratory study had been completed.

Because of the limited research available, the experiment tested as many stoppers as possible, and I included the most popular stoppers from the stopper usage survey. Because some of the stoppers have a hefty price tag, non-cork stopper players, stopper makers, and flute stores provided some of the test stoppers. As a result of their generosity and cooperation, four of the most popular stoppers were included in the experiments (Robert Bigio's Stopper; Celestine Rexonator, the "Balance" model; Seidman Flute Stopper Plug; and the traditional cork stopper), plus the Swap-Stopper. The Swap-Stopper was included because it is an interesting and novel design, created by one of Bigio's students, Peter Robertson.

Performers

To produce high-quality results and consistent sampling, it was important to include skilled and reliable flutists in the playing tests. Four professional flutists who regularly perform with The Phoenix Symphony were willing to participate in my experiments. Since I would be exchanging the stoppers, I did not participate in the study. The four flutists performed and recorded two very similar playing tests, first in a recording studio (for the acoustic analysis), and second in a large acoustically treated rehearsal room, which would have slightly more reverb (for the listeners' perception test). Because the experiment was blind, the flutists were wholly unaware of which stoppers were included in the experiment, let alone which stopper they were playing. The flutists could perceive a difference in the headjoint's weight, but because they were performing on an unfamiliar flute (see Test Flute, below) and could not see the stoppers, there was no way to identify which stopper was which.

Test Flute

After deciding which stoppers would be included, another question had to be answered: Do the flutists play the same flute, or do they each use their own? I decided that keeping the flute constant would present clearer data on the differences between the stoppers. As headjoint cut has such a large impact on timbre and projection, chances were good that using different headjoints would make it impossible to differentiate the stoppers' effects from the headjoints' effects.

The first playing test included four long tones and a three-octave chromatic scale from C4 to C7 repeated with varying dynamics. The second playing test was identical, but included an additional melodic tone exercise from Moyse's *24 Little Melodies*,[85] and an articulation example: the popular orchestral excerpt from Mendelssohn's "Scherzo" from *A Midsummer Night's Dream*.[86] The stopper order was initially randomized, but for ease and accuracy of installation and exchange, I kept the same order for each player. Two different, random orders were used for each of the two playing tests, and the flutists played the stoppers in the same order.[87]

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[85] Marcel Moyse, *24 Little Melodic Studies* (Paris: Alphonse Leduc, 1932).
[86] Felix Mendelssohn, *Midsummer Night's Dream, Op. 61* (Leipzig: Breitkopf und Härtel, 1842).
[87] The flutists performed with the stoppers assigned to these numbers in this order for Playing Test 1: 5, 4, 2, 1, 3. The flutists performed with the stoppers assigned to these numbers in this order for Playing Test 2: 1, 3, 2, 5, 4.

The flutists were given a few moments to try out the stopper before recording the playing test, but ultimately tested the capabilities of each as they were being recorded. After playing through the test on each stopper, the players completed a questionnaire about their perception and opinions on the stoppers.

The playing test examples were based on a similar study conducted by Linortner in 2001.[88] In this experiment, he examined the potential effects of tubing material, and if musicians could correctly identify different tubing materials by listening. Similar to his perception test, I included a three-octave chromatic scale from C4 to C7 and four long tones with different dynamics. Specifically, flutists played A4, F5, D6, and B-flat6 at a comfortable forte, a crescendo to *fff*, and a decrescendo to *ppp*, and two orchestral excerpts. These pitches were chosen because they evenly divide the flute's most used-range of pitches.

In the stopper experiments, all of the playing test material was performed without vibrato, except for the tone and articulation examples performed in the second playing test: Moyse's first melody and variation from *24 Little Melodies* and orchestral excerpt from Mendelssohn's *Scherzo* (2 measures before Rehearsal P to the end). This material was included because it would test each stopper's range of capabilities, without the length being so tiring that flutists would become overly fatigued as they performed it on five different stoppers (which would affect the quality of the data).

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[88] Linortner, Renate, "Silver, Gold, and Platinum: Wall Material and the Sound of the Flute."

Equipment Used

Each of the four flutists performed the playing tests on my personal flute, which is a professional Powell Custom flute with the Philharmonic headjoint cut. It is all silver with soldered tone holes, and includes a platinum riser. Additionally, it has a B foot and a standard wall thickness (tube thickness) of 0.016".

Recordings were made using an Earthworks M30 microphone, a Sound Devices USBPre2 audio interface/preamp, and Praat software running on a Windows 10 computer. Mono audio samples were recorded at 96 kHz with 24-bit depth and saved as uncompressed WAV files. The microphone was consistently located approximately 27 inches from the lip plate and about a foot above the headjoint to minimize air noise in the sound.

Minimizing Variables

I attempted to keep the number of variables as low as possible in these experiments. To do this, each player used the same flute, the same stoppers and, when possible, the stoppers were used with the same crown. I used the Bigio installation tool to easily install and remove the stoppers, which is a hollow metal cylinder marked with three lines intended to assist flutists in placing the stopper in the correct location (see the left side of Figure 36). To make it even easier to swap out the stoppers, I marked the end opposite the lines with a piece of tape that allowed for maximum accuracy and efficiency when placing the stoppers in the correct location.

Figure 36. Bigio Installation Tool

Crowns

Crown type could not always be controlled because some of the stopper mechanisms required the use of a specific crown. However, I was able to minimize the number of crowns, and used three crowns alternately among the five stoppers. Using different crowns introduced another weight variable, but this was preferable to foregoing the crown completely because I needed to use crowns to evaluate the stopper makers' claims, which assumed the use of a compatible crown.

The Celestine Rexonator and Seidman Flute Stopper Plug are designed to replace the cork on the threaded rod, so these stoppers were added to a rod with a traditional silver crown. Because I used my personal cork stopper in the experiments and it is permanently glued to the rod and metal disks, the Celestine Rexonator and Seidman Flute Stopper Plug had to be used on a different threaded rod than my cork stopper. This worked out perfectly well, and the only down side was that the threads were different on the two rods, which meant that it was not possible to use the same crown for both of the threaded rods. I used two slightly different crowns for the cork stopper and the Celestine/Seidman stoppers.[89]

[89] Both crowns were silver. The crown for the cork stopper weighed 12.54g, and the crown for the Celestine and Seidman stoppers weighed 11.31g.

Lastly, both the Bigio Stopper and Swap-Stopper do not utilize or include threaded rod in their design, so it was not possible to use them with a traditional crown. Instead, I followed the makers' recommendations and used the Bigio Crown with both the Bigio Stopper and Swap-Stopper.

The remaining variables were minimal, including the time of day of the recording sessions, the amount of time playing the stoppers, and the air conditioner noise in the room. The players were given a few moments to familiarize themselves with the stopper before they recorded the playing test. Although this amount of time varied slightly from person to person and stopper to stopper, it was generally about 20 seconds before the player decided to start the recording. During the recordings, tempos varied a moderate amount, and examples were sometimes re-recorded. This meant that the time spent playing the stoppers varied slightly, but was unlikely to vary enough to impact the quality of the data.

Acoustic Experiment Design

The acoustic experiment took place at Tempest Recording in Tempe, Arizona. This location was isolated enough to produce clean sounds that would not be negatively affected by background noise or require sound editing. It was also dry enough that the sound would not be contaminated with exaggerated reverb, as can happen in a recital or concert hall. Many similar acoustic studies were conducted in an anechoic chamber, but an anechoic chamber would likely have been unsettling to the players, who would already be performing a difficult playing test on a new instrument and new stoppers.[90] Collecting characteristic perception data from the players would be useful, so the recording studio was chosen as an ideal compromise between sound quality and player comfort.

After the recordings were complete, I analyzed the sound files and ran a spectral analysis. The playing test was designed to analyze the following characteristics of the playing test examples:

- Crescendo to *fff* (A4, F5, D6, and B-flat6 long tones): Maximum intensity
- Decrescendo to *ppp* (A4, F5, D6, and B-flat6 long tones): Minimum intensity
- *fff* chromatic scale: Maximum intensity and centroid of each note
- *ppp* chromatic scale: Minimum intensity and centroid of each note

Sampling

To analyze the recordings, I used the Adobe Audition software application to locate and record the timestamps and marked the beginning and endings of each long tone.[91] For the chromatic scales, a sampling location was chosen in the middle of each note after the turbulence of finger technique or response and room reflections had passed. The notes were all long enough that sampling could include a 50 millisecond (ms) slice of each note in the ascending chromatic scales at both *fff* and *ppp*.

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[90] Zora Schärer Kalkandjiev and Stefan Weinzierl, "The Influence of Room Acoustics," *Psychomusicology: Music, Mind, and Brain* 25, no. 3 (2015): 195-207, accessed on March 24, 2020, http://dx.doi.org/10.1037/pmu0000065.
[91] Adobe Systems, Adobe Audition, Version 13.0.5.36, computer program, accessed March 24, 2020, https://www.adobe.com/products/audition.html.

Once the timestamps were determined, the sound recordings were analyzed with the Praat software application,[92] a speech analysis program that Gardner uses in his experiment on the lined joints of clarinets.[93] Spectral centroid (or center of gravity, as the program calls it) is the average frequency of a sound, weighted by the amplitude of each of its spectral components.

Praat calculated the spectral centroid from a fast Fourier transform (0 to 45 kHz) for each 50 ms Gaussian window of the recorded notes in the chromatic scales. Intensity values were measured at 1 ms intervals, with each value being a weighted average from 10.6 ms (0.8/minimum pitch (75 Hz)) Gaussian windows. The mean energy averaging method was used in Praat to calculate average intensity values from the 50 ms samples. The results of the acoustic analysis in Praat can be found in the following chapter.

Perception Test Design

The perception studies included three tests: the player's perception questionnaires for Playing Test 1 and 2 and the listener's perception questionnaires for the listening test. Each part was blind and randomized—neither the players nor the listeners knew which stopper they were evaluating.

A 5-point Likert scale was used for the majority of the perception test questions, where 1 represented "Strongly Disagree" and 5 represented "Strongly Agree." The Likert scale was chosen because it produced clear results and helped

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[92] Paul Boersma and David Weenink, Praat: Doing Phonetics by Computer, Version 6.0.37, computer program, accessed March 24, 2020, http://www.praat.org/.

[93] Joshua Gardner, "Effects of a Synthetic Clarinet Bore Liner on Spectral Centroid and Fundamental Frequency Error," *Acta Acoustica* 105, no. 6 (December 2019): 1206-1216, accessed on March 24, 2020, https://doi.org/10.3813/AAA.919397.

quantify qualitative data. Language and semantics can vary greatly when describing sound perception, and each word can have a different meaning to different people. Short-answer questions were avoided in the questionnaires because the language needed to be standardized to produce high-quality results. However, the questionnaires included a space to write additional comments because I wanted the players and listeners to be able to note anything they perceived that was not included in the Likert scale questions.

Listener Perception Test

For the listeners' perception test, the mode of listening needed to be determined. There were two options: (1) everyone listens with the same headphones, or (2) they listen over the same speakers in the same room. Listening with headphones meant that each listener had to be scheduled individually, which would limit the feasible sample size of the listeners. Instead, it was determined that the musicians would listen over speakers, which meant that many listeners could participate simultaneously. Scheduling professional flutists at the same time would be challenging, so instead, the sample for the two listening tests included Arizona State University's flute studio class. This allowed everyone to listen simultaneously in the ASU Recital Hall with the built-in speakers.

Listening Examples

The listening test recordings were normalized to -3 dB, to minimize the dynamic differences between the players. The recordings were also trimmed, to ensure that the listening test would fit into the time allotted. Specifically, the shortened material included measures 11 through 16 of the Moyse example and 2 before P to the downbeat of 4 before Q of the Mendelssohn excerpt.

Listening Test Sample

The listening sample included musicians who were all majoring or minoring in music, had completed music degrees in the past, or were taking non-major flute lessons. Their music education experience included Bachelor's, Master's, and Doctoral degree programs, and participants were ages 18-55.

Listening Questions

The listening test was designed to evaluate the stopper's: (1) overall loudness; (2) capacity to play softly; (3) stability at the softest dynamics; (4) brightness; (5) focus; (6) tone quality; (7) tone quality consistency in all registers; and (8) clarity of articulation. These characteristics were included because they were also the factors flutists would evaluate most seriously when considering a change in equipment. The questions included in the perception test can be found in Appendix C.

Recording Errors

There were two small errors in the recording process that were minimized, to avoid compromising the quality of the listening test data. While recording the playing tests, I encountered an unexpected buffer issue in Praat that arose for a player during one of the playing tests. Player D played the tone example at a much slower tempo than that utilized for the other flutists, which meant that one articulation example after it was cut short after the buffer filled. Unfortunately, this error was discovered after the recording session had been completed. However, the short articulation example was repeated four times during the listening test to allow listeners to evaluate the clarity of articulation. The other error included a forte chromatic scale not recorded in one playing test, which listeners were warned about beforehand so they could listen to the remaining forte section of the playing test more critically.

Player Perception Test

The questionnaire after each playing test was an invaluable opportunity to test the players' perception of the stoppers. It allowed me to determine if there were any differences between the players' perception and the listeners' perception, which was suspected to vary. Players would experience both tactile and aural stimuli, and they would perceive the sound very close to where the sound was being produced. Listeners, on the other hand, would be perceiving the sound from farther away and would not perceive any tactile stimuli.[94]

Similar to the listening test, the perception test questions utilized the 5-point Likert Scale (from "Strongly Disagree" to "Strongly Agree") and a space for additional comments. This seemed the best way to turn perception-based data into something that could be quantified, and allowed the language and terminology used by participants to remain consistent. The players' perception test questions can be found in Appendix B.

[94] The microphone was located approximately 27 inches from the player.

CHAPTER 6

STUDY RESULTS

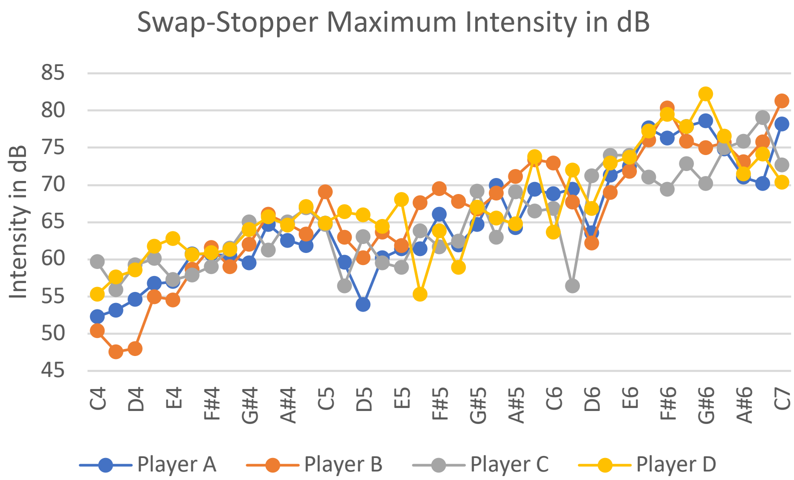
Acoustic Experiment Results

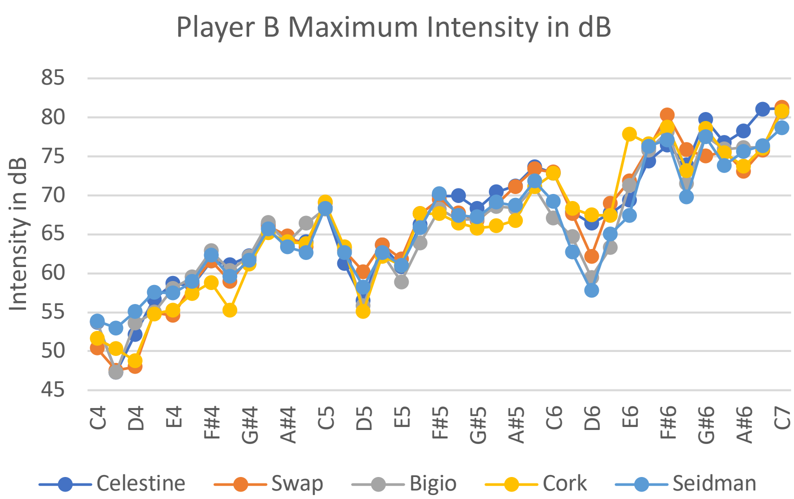
The playing test recordings and the resulting acoustic analysis in Praat was designed to answer two research questions: Do stoppers have an effect on intensity or spectral centroid (also known as brightness)? The Praat software used to analyze the recordings defines intensity as "the intensity in air, expressed in dB relative to the auditory threshold."[95] Consistent with the results of previous experiments, the greatest variation in intensity and spectral centroid was found between the players, not the stoppers. This is illustrated in the two characteristic examples in Figure 37.

Because of the variation between the players, comparing the stopper recordings of each individual player was the clearest way to evaluate the differences between the stoppers without being clouded by player influence. This eliminated the player influence variable, and kept the stopper influence more prominent. If I instead compared all of Stopper 1's recordings, I would be more likely to discover difference between the players, and it would not be possible to identify the differences between the stoppers.

[95] Paul Boersma and David Weenink, Praat: Doing Phonetics by Computer.

Figure 37. Comparing Stopper and Player Effect





Intensity Range

First, it was interesting to observe the dynamic range of the flute (in dB), as produced by some of the highest-caliber players. The dynamic range of the minimum and maximum intensity examples ranged from 25 to 82 dB, with a span of about 57 dB. The maximum intensities were very similar in the chromatic scale and the long tone crescendo to maximum. However, the minimum intensities of the long tone decrescendo to minimum reached 25 dB (6 dB softer than the *ppp* chromatic scales).

Although the peaks and valleys found in intensities varied greatly by player, the players' personal trends were relatively consistent from stopper to stopper. Intensity valleys in the chromatic scales that were consistent across all of the players included D5, D6, and B6. No clear trends in intensity peaks were present, but variability increased at F6 and above, both from player to player, and stopper to stopper.

Maximum Intensity

To determine the degree of influence stoppers had on maximum intensity, the peak intensity of the long tone crescendos were averaged together, and the standard deviation in dB was calculated. The greatest deviation in the maximum intensities of the stoppers was 8.42 dB, which would almost be perceived as a doubling of loudness (10 dB can be perceived as a doubling of loudness).[96] In comparison, 5 dB is "clearly perceptible," and 3 dB is "just perceptible," although this does depend on frequency. Although 8.42 dB was the greatest variation, the players' average variation in maximum intensity was about 3.5 dB, which suggests that the stoppers had a "just perceivable" effect on maximum intensity overall.

Figure 38 illustrates the average maximum and minimum intensity by stopper and the standard deviation, when grouped by player. In general, there was a

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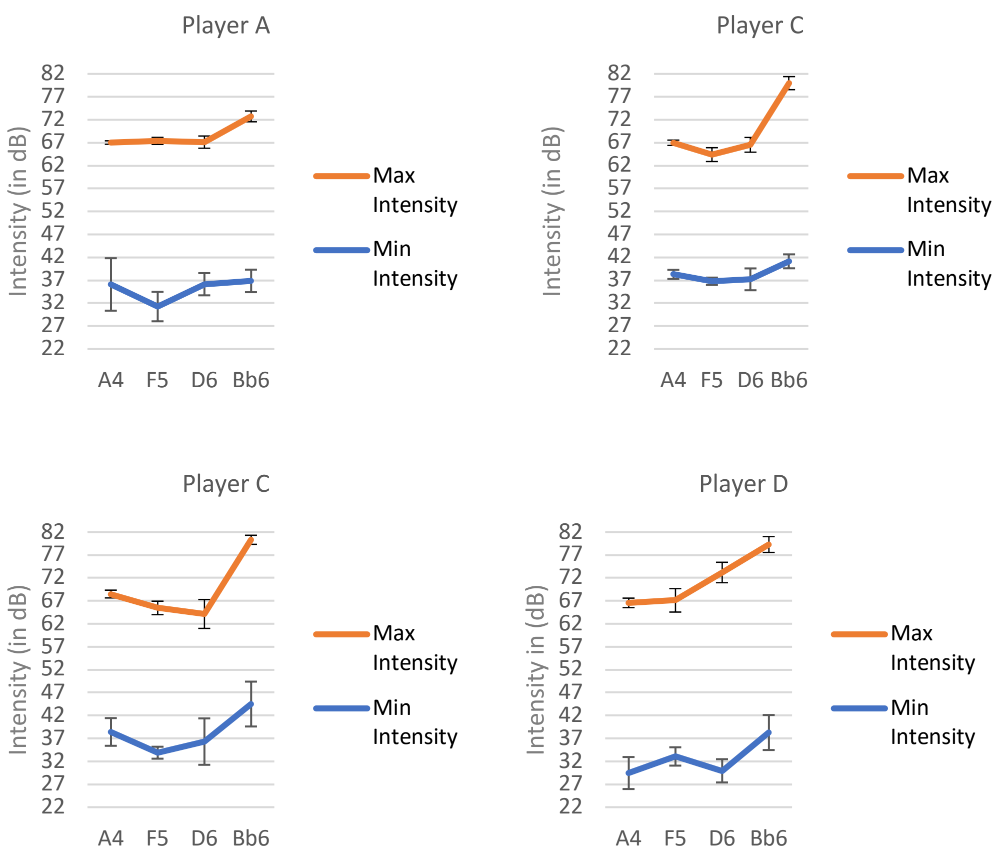
[96] Enda Murphy and Eoin A. King, "Principles of Environmental Noise," in *Environmental Noise Pollution* (Elsevier, 2014), accessed on March 24, 2020, https://doi.org/10.1016/C2012-0-13587-0.

greater standard deviation for the minimum intensity examples than the maximum intensity examples.

Figure 38. Average Max and Min Intensity in dB and Standard Deviation

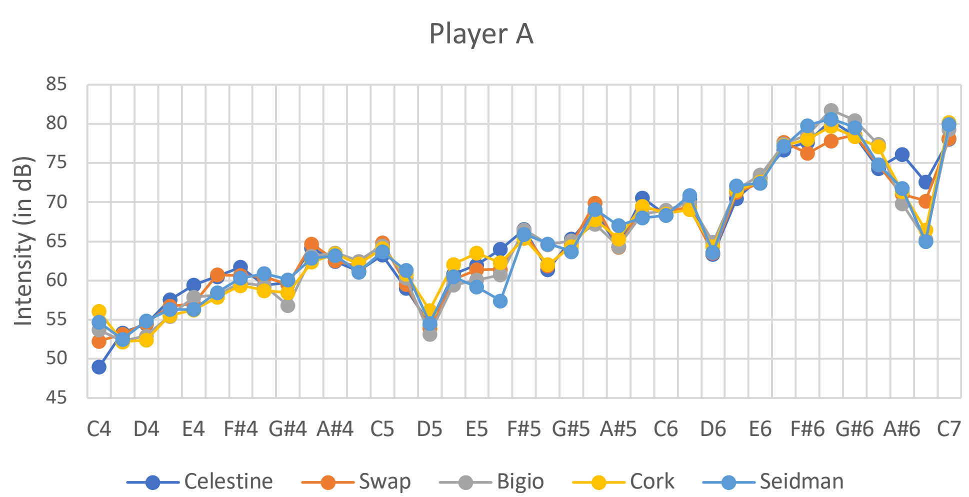


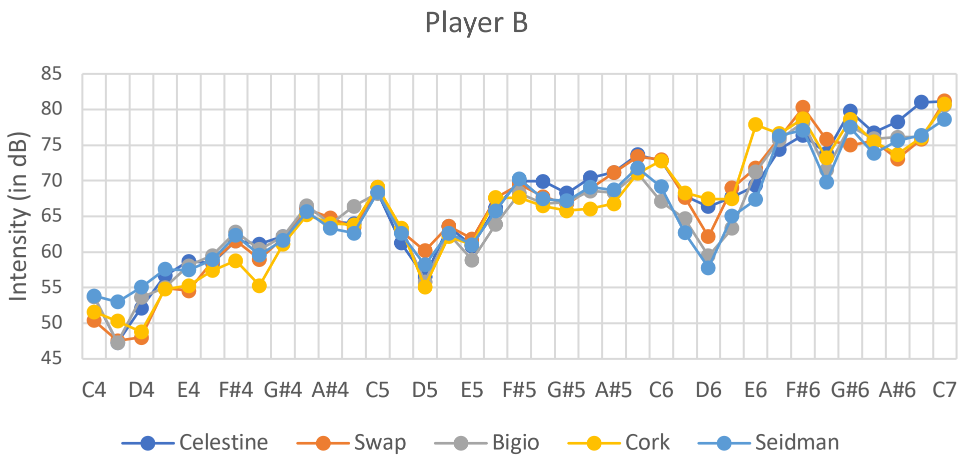
The average maximum intensities helped determine the overall effect of stopper on maximum intensity. When observing the maximum intensities more closely by comparing the long tone crescendo and *fff* examples of each of the players, I expected to observe trends that were consistent for all of the individuals. This was not the case. Instead, the individual stopper's effect on the player became more obvious. The stoppers' effects on the player are summarized in Figure 39, and the source intensity charts can be found in Figure 40.

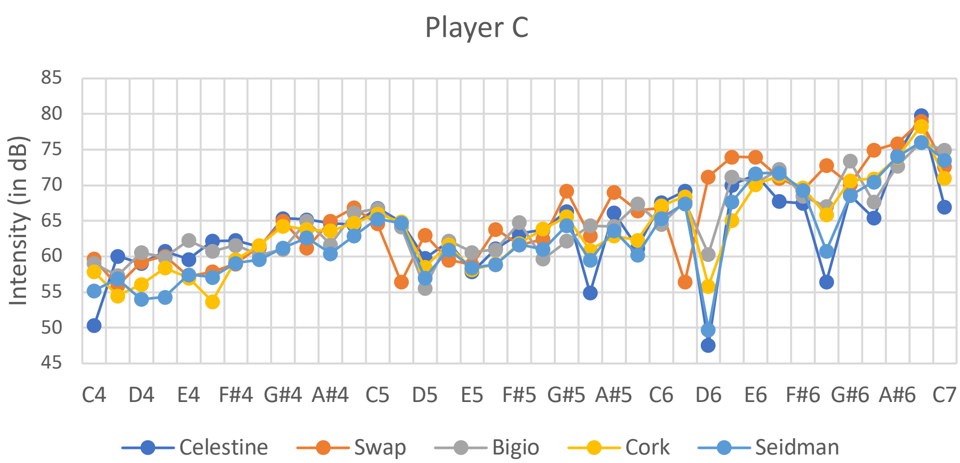
Figure 39. Stopper Effects on Maximum Intensity

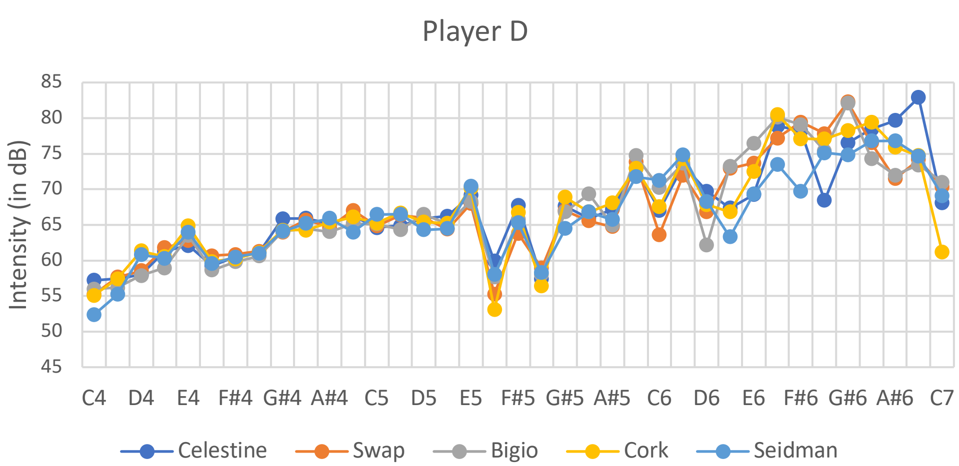
Player	Celestine	Swap	Bigio	Cork	Seidman
A	Smoothest intensity contours.	Highly variable. Sometimes loudest, softest, or average.	Highly variable. Sometimes loudest, softest, or average.	Average to low side of maximum intensity.	Most susceptible to intensity valleys.
B	Above average above G-sharp6	Average.	Average.	Highly variable. Both susceptible and resistant to valleys.	Highly variable. Above average until F-sharp5, then below average.
C	Below average G6 and above.	Average, strong valleys at C-sharps.	Average.	Below average until C6, then above average.	Below average.
D	Above average above A6.	Average.	Average.	Average.	Below average above G-sharp5.

Figure 40. Maximum Intensity in dB



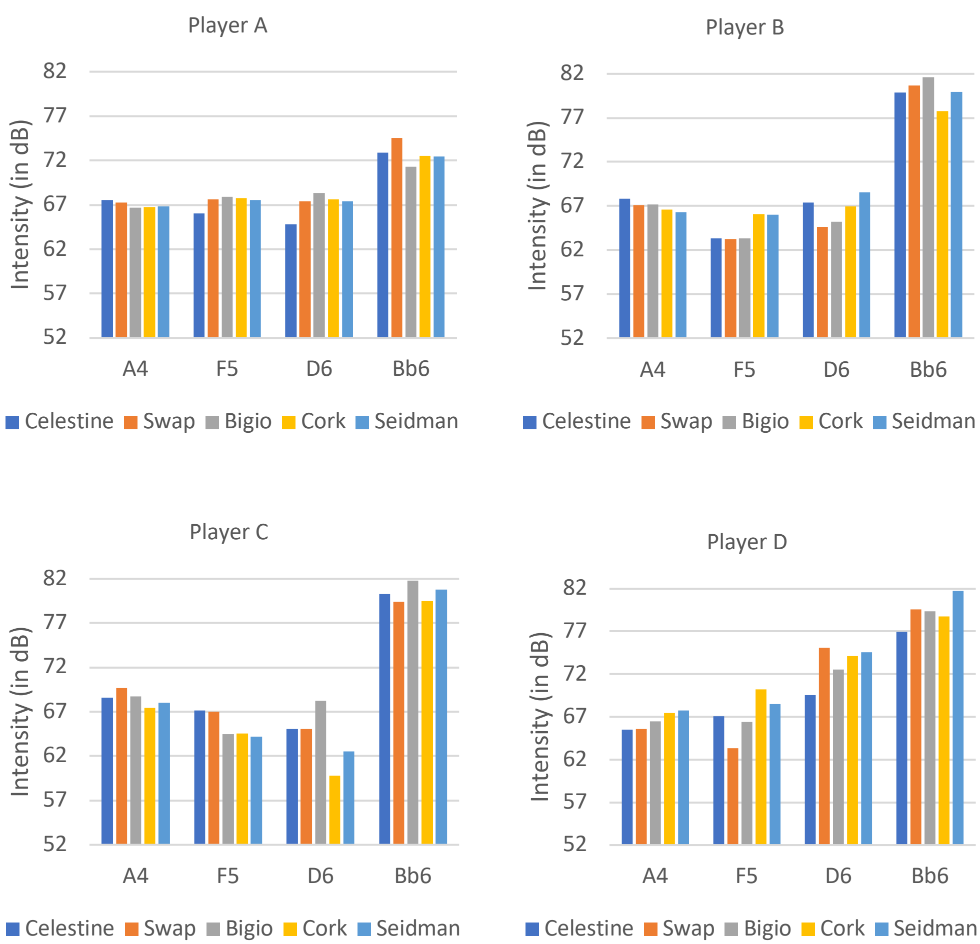

Player B
Intensity (in dB)
85
80
75
70
65
60
55
50
45
C4 D4 E4 F#4 G#4 A#4 C5 D5 E5 F#5 G#5 A#5 C6 D6 E6 F#6 G#6 A#6 C7
Celestine
Swap
Bigio
Cork
Seidman


Player C
Intensity (in dB)
85
80
75
70
65
60
55
50
45
C4 D4 E4 F#4 G#4 A#4 C5 D5 E5 F#5 G#5 A#5 C6 D6 E6 F#6 G#6 A#6 C7
Celestine
Swap
Bigio
Cork
Seidman


Player D
Intensity (in dB)
85
80
75
70
65
60
55
50
45
C4 D4 E4 F#4 G#4 A#4 C5 D5 E5 F#5 G#5 A#5 C6 D6 E6 F#6 G#6 A#6 C7
Celestine
Swap
Bigio
Cork
Seidman

When comparing the maximum intensities of the long tone crescendos, each stopper produced similar maximum intensities, only varying by a few dB (see Figure 41). Because the players had the greatest control over the long tones, the data collected from the long tones best illustrate the maximum intensity capabilities of the stoppers. The variation in maximum intensity varied slightly, as mentioned before, but the small variation present was not consistent across the players. This suggests two possibilities: (1) the stopper has no effect on maximum intensity or (2) the stoppers are affecting each of the players differently.

Figure 41. Long Tone Maximum Intensities in dB



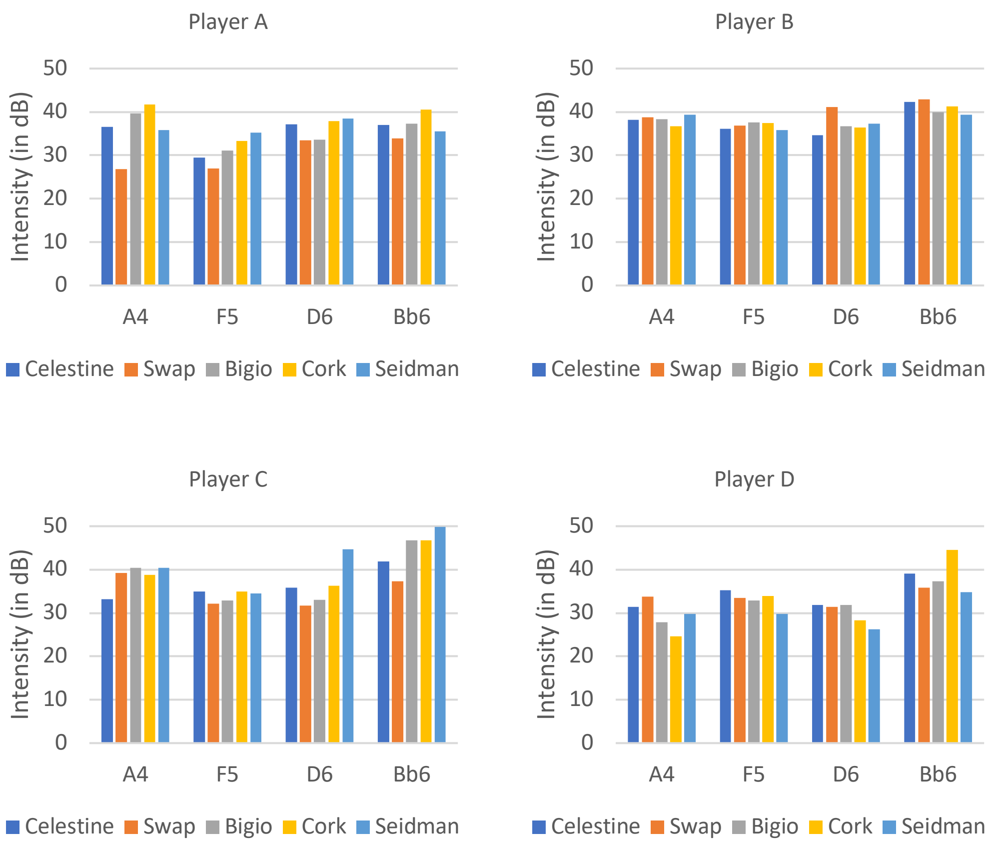
Minimum Intensity

Interestingly, the players' long tone decrescendos to a minimum intensity were moderately softer than the minimum intensity they were able to achieve in the chromatic scales. In the long tone examples, the players were focusing entirely on achieving the softest possible dynamic of one note, which produced the most reliable minimum intensity data. The minimum intensity for all of the long tones across all of the players and stoppers was 24.56 dB, with an average minimum of 29.42 dB. This was significantly lower than the softest intensity achieved by all players and stoppers in the chromatic scales (31.63 dB).

To determine the minimum intensities of the long tones, I used Praat to find the last timestamp with an identifiable frequency. When the pitch became unidentifiable, I noted the timestamp before it (back one hundredth of a second, 0.01 s) and used this timestamp to calculate the minimum intensity of the sample with an identifiable pitch.

Similar to maximum intensity, I organized the data by player and compared the minimum intensities produced with each stopper (see Figure 42). The minimum intensities varied between the stoppers from as little as 2.68 dB (Player B) to as much as 12.95 dB (Player C). Unsurprisingly, the stoppers that produced the softest dynamic varied greatly between the players. This suggests that the stoppers have no perceivable impact on minimum intensity. Furthermore, none of the stoppers seemed to perform best or worst for a particular player. The only exception was for Player A, for whom the Swap-Stopper consistently produced the softest minimum intensity.

Figure 42. Long Tone Minimum Intensities in dB



Spectral Centroid

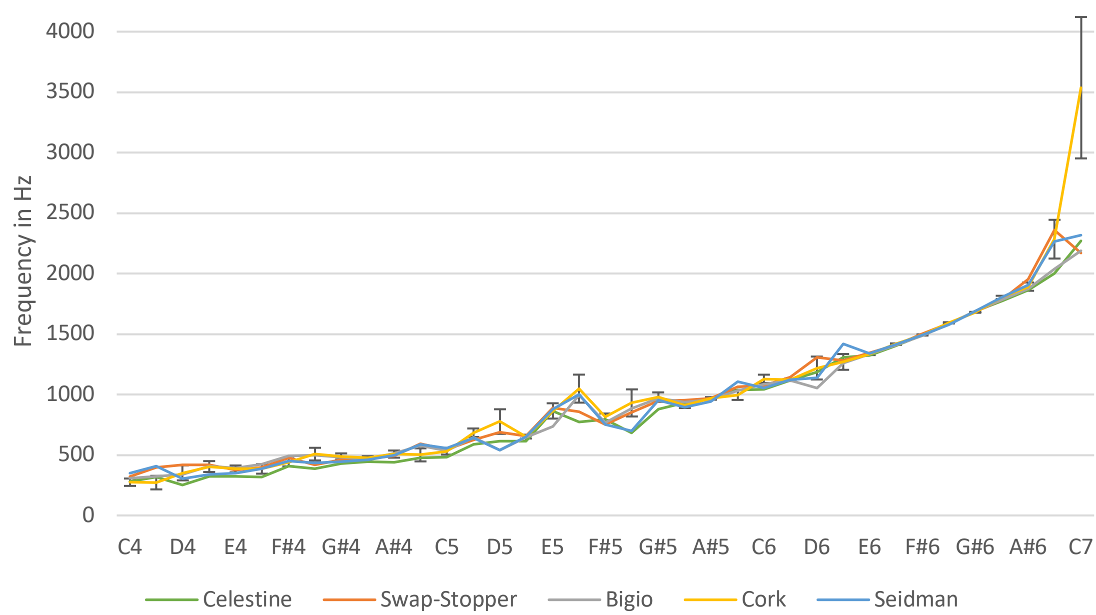
The second research question sought to determine if stoppers play a role in brightness. Praat was used to calculate the spectral centroid of each individual pitch in the C4 to C7 chromatic scale played at *ppp* and *fff*. Spectral centroid was chosen to measure brightness because it is proven to be an accurate indicator of perceived brightness.[97] When observing the spectral centroid of the *ppp* chromatic scale, the

[97] Emery Schubert and Joe Wolfe, "Does Timbral Brightness Scale with Frequency and Spectral Centroid?."

brightnesses were remarkably similar, regardless of player or stopper. Slight variation in centroid scores was present until the last third of the chromatic scales, where the brightnesses became nearly identical (see Figure 43).

To observe the effect stopper has on centroid overall, the centroid of all of the players were averaged, and the standard deviation was calculated. The greatest variation was found in four different pitches: D5, F5, B6, and C7. In particular, the cork stopper had a sudden spike in brightness at C7, which was not found in the other stoppers. However, little deviation was present in the spectral centroid scores, which suggests that stopper has little influence over brightness.

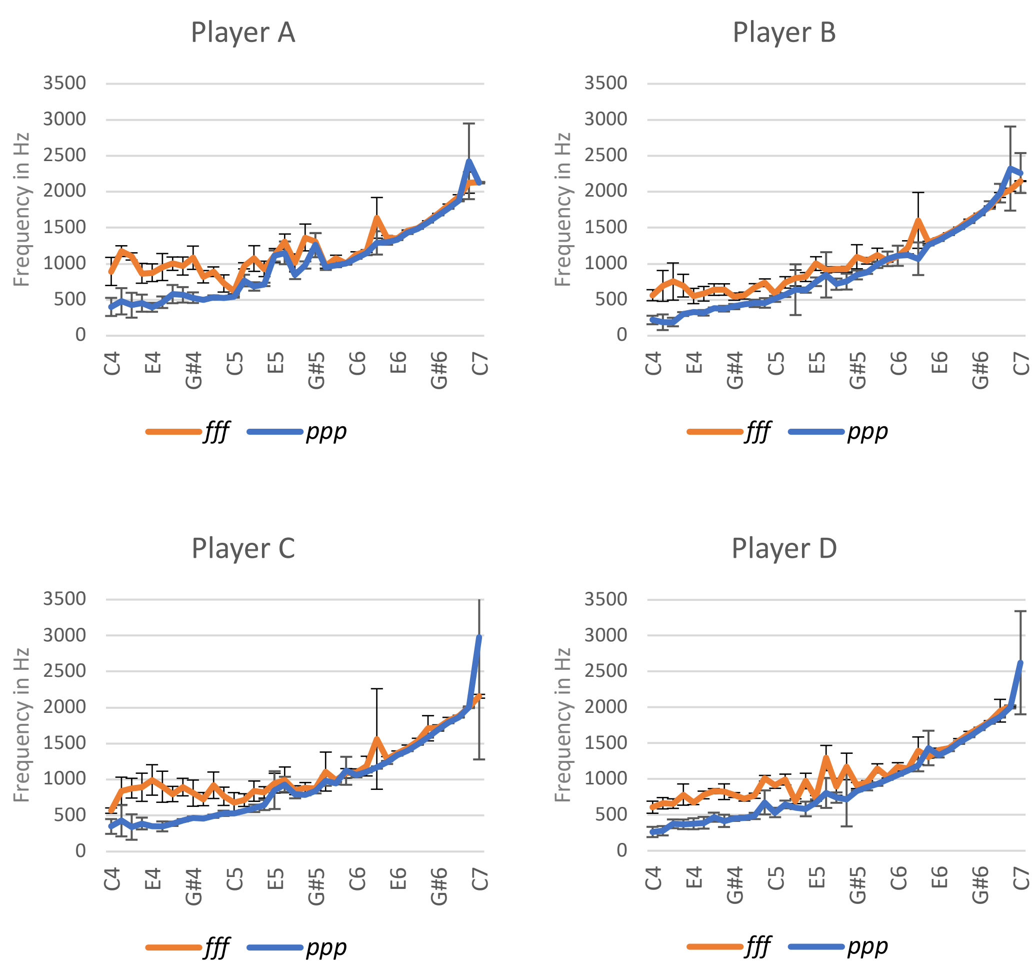
Figure 43. Average Spectral Centroid in Hz and Standard Deviation



Like intensity, the five stoppers' spectral centroid results were compared within each player. The stopper centroids were averaged across the stoppers, and the standard deviation was used to identify the amount of variation between the stoppers (which can be found in Figure 44). Overall, the variation between stoppers and players was minimal.

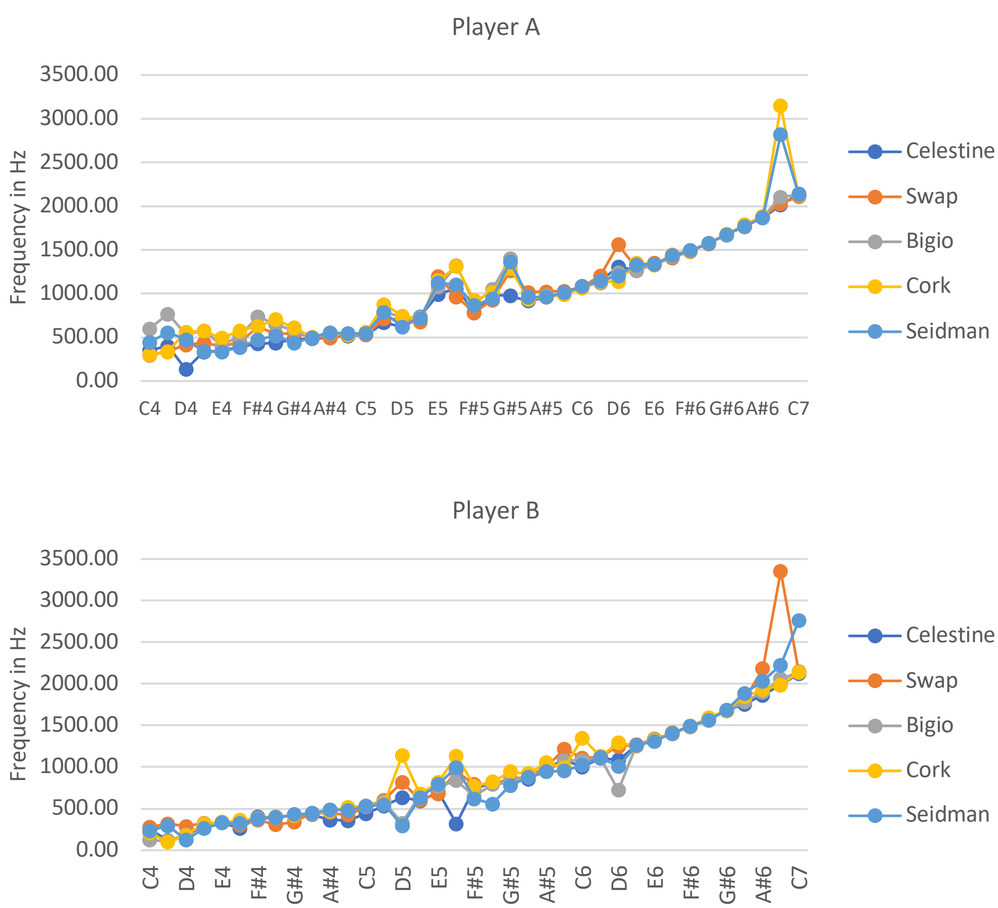
Interestingly, there was greater centroid variation in the *fff* scales than *ppp*, which suggests that (1) playing with a maximum intensity may have affected the stoppers' brightnesses differently (a trend that was lesser at a minimum intensity), or (2) that the physiological mechanisms controlling the sound were more difficult to control at a maximum dynamic.

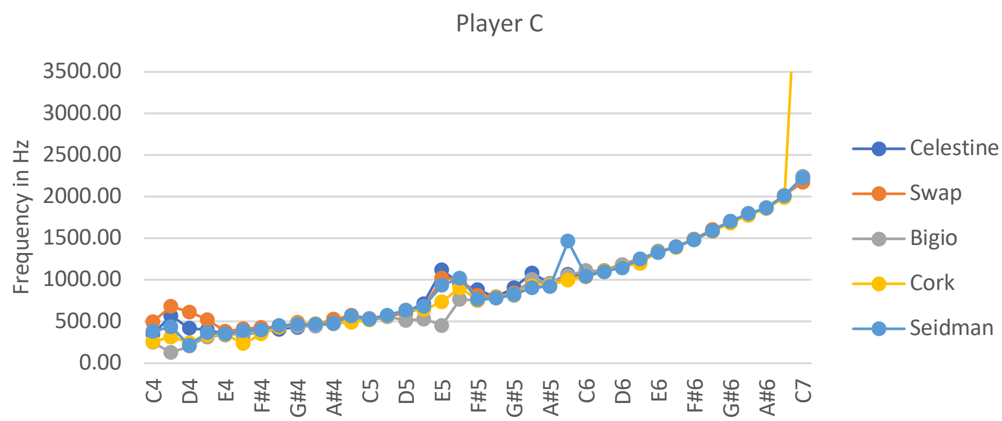
Figure 44. Average Centroid and Standard Deviation in Hz

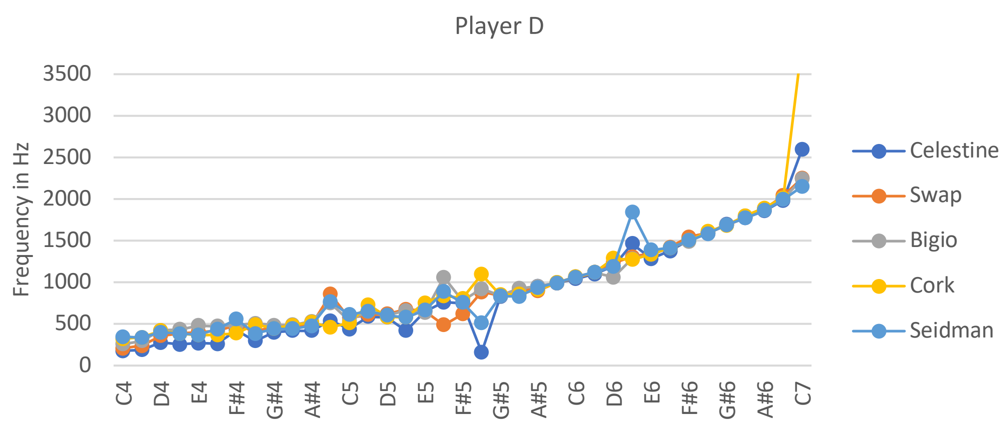


The individual spectral centroids of each stopper were also organized by player (see Figure 45). Although these graphs allowed for more detailed examination than the averages above, there was still little worth noting. Occasionally, brightness peaks stood out from the rest. This was most frequently observed with the cork stopper, but also occasionally occurred with the Swap-Stopper, Bigio, and Seidman stoppers as well. The Celestine Rexonator most often produced an average brightness, but it was occasionally observed in brightness valleys that fell below the rest of the stoppers.

Figure 45. Spectral Centroid in Hz







Although it seems that the stopper only minimally affects brightness and intensity, stoppers may influence human perception of brightness or timbre. This hypothesis was tested in the players' and listeners' perception tests.

<u>Perception Test Results</u>

This experiment also explored the stopper's effect on human perception, both as a player and as a listener. The players completed a perception questionnaire after each playing test, first in a recording studio and next in a classroom. Listeners completed a similar questionnaire for the listening test where they evaluated recordings normalized to -3 dB (to minimize the dynamic differences between the players). However, only the listening test recordings were normalized. The acoustic analysis recordings were unaltered.

Statistical Analysis

To statistically examine potential perception differences between stoppers, three separate one-way Analyses of Variance (ANOVA) were performed with stopper type as the independent variable and projection, ideal tone quality, and clarity of articulation as the dependent variables respectively. Due to the small number of players (n = 4), I did not statistically test differences amongst players only.

For these ANOVAs, each participant's scores (listeners and players) for each stopper were averaged across players, resulting in one score for each stopper for each listener and player. This approach was utilized to avoid violations of assumptions of data independence (i.e., to avoid multi-level data analysis). Results of the ANOVAs indicated that there were no statistically significant differences in scores for projection, $F(4, 85) = 1.31$, $p = 0.27$, ideal tone quality, $F(4, 85) = 1.33$, $p = 0.26$, or clarity of articulation, $F(4, 85) = 1.32$, $p = 0.27$, between the stoppers for players or listeners. A second set of ANOVAs was conducted with player ratings of projection, ideal tone quality, and clarity of articulation included in the dataset (in addition to the listener perception scores on these variables). Again, stoppers produced a non-significant effect on any of the variables. Thus, stoppers do not affect perception statistically.

Player Perception Test Results

Although the statistical analysis found no perceivable differences between the projection, tone quality, and clarity of articulation between the stoppers among players and listeners, there was one area that varied greatly that is worth discussing: “fit.” In the players’ questionnaires, I included a question that asked them to rank how well they felt the stoppers “fit” their playing style and produced ideal results: “I feel that this stopper is a good “fit” for me. It feels comfortable to play and produces the effects I expect and prefer.” These results not only had extreme variation between the players, the scores also tended to vary from Playing Test 1 to Playing Test 2, which can be seen in Figure 45 below. Only twice did a player give a stopper the same “fit” rating between both tests. “Fit” scores between the two tests often varied by 2 or more points.

Figure 46 lists each player’s “fit” score for each stopper in the first and second playing test. A score of 1 is the lowest possible “fit” score and a 5 is the highest. The color gradation represents the rank of each stopper when compared to the others in each playing test. Yellow represents the lowest “fit” score of the five stoppers, and the dark green represents the highest “fit” score. For example, Player A felt that the Swap-Stopper had the best “fit” and the Bigio Stopper had the worst “fit” in Playing Test 1.

Figure 46. Fit Ratings for Playing Test 1 and 2

	Player A		**Player B**		**Player C**		**Player D**	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Bigio	1	4	2	4	4	2	4	1
Cork	4	4	2	3	5	1	5	3
Seidman	2	5	2	3	1	4	5	4
Swap	5	2	4	2	3	4	4	4
Celestine	3	2	2	1	4	1	2	2

Based on the players’ responses and their detailed comments, they were perceiving strong sensory input from these stoppers in both positive and negative ways. Because players seemed to have strong and varying opinions on “fit,” I believe having a stopper that is a good “fit” becomes even more important.

Listening Test Results

To get an idea of which stoppers performed the best overall, I averaged all of the listeners' scores between all of the players. This was intended to determine if any of the stoppers performed well for all of the players (excluding brightness). Figure 47 compiles the listeners' averages for the stoppers in the different categories. The possible range of scores are 1 to 5, with 1 being "Strongly Disagree," and 5 being "Strongly Agree." The color scales were added to assist in seeing the variation and rank of the scores. Brightness was given a different color, because a higher score is neither good, nor bad.

Figure 47. Players' Averaged Responses to the Performance Criteria

	Projection	**Soft Overall**	**Stable Piano**	**Bright**	**Focused**	**Ideal Tone**	**Consistently Ideal**	**Clear Articulation**
Bigio	3.607	3.714	3.571	3.304	3.702	3.714	3.696	3.946
Cork	**3.768**	3.732	3.643	3.412	3.821	**3.964**	**3.875**	**4.089**
Seidman	3.607	**4.109**	**3.800**	3.364	**4.018**	**3.964**	**3.927**	**4.036**
Swap	3.321	4.000	**3.786**	3.464	3.614	3.768	**3.839**	3.930
Celestine	3.607	3.643	3.554	3.446	3.750	3.804	3.768	3.768
Range	0.45	0.47	0.25	0.16	0.40	0.25	0.23	0.32

According to the 14 participants, the traditional cork and Seidman Flute Stopper Plug both performed the best overall, which may indicate that these stoppers have the highest chance of performing well for the greatest number of players. However, many categories included a small range in scores because the participants' responses were highly varied. The categories with minimal variation in scores included brightness, consistently ideal tone quality, piano stability, and ideal tone quality, which suggests that stoppers do not have a perceivable effect on these areas. The categories with a variation of 0.3 points or greater included overall projection, softness overall, focus, and clarity of articulation. It is possible that these areas were affected by the stopper, but the variation in overall projection and softness were not present in the results of the acoustic analysis.

To determine if the listeners agreed upon which stopper performed the best for each player, I examined the listeners' scores for individual players. The listeners' range of scores for each stopper varied by an average of 2.7 points on average on a scale of 1 to 5, which suggests that listeners cannot accurately perceive a difference between the stoppers consistently or cohesively as a group.[98]

[98] On the listening questionnaire, 3 points would be the difference between "Strongly Agree" and "Neither Agree nor Disagree."

CHAPTER 7

CONCLUSION

Recent non-cork stoppers have expanded the function of the stopper beyond its traditional role as a seal and allow further customization of the flute. Although the effects of the stopper have been relatively unexplored to date, flutists are very curious about its effects, especially if they appear in published studies on the results. The history, stopper usage survey results, relevant experiment results, and my single-blind study results included in this dissertation may offer flutists insight into stopper makers' claims and help them choose a stopper that creates desirable effects.

The results of these studies may or may not convince players to try or permanently switch to a non-cork stopper. However, it should be noted that none of the stoppers had a detrimental effect on the performance categories. Even when the players ranked the "fit" score as low, the listeners often still ranked the performance categories highly.

Although my single-blind studies ultimately found little statistically significant evidence of differences between stoppers, acoustically or perceptually, the lack of differences demonstrated in this study can also be translated into no perceivable *negative* effect. If flutists feel that a stopper works well for them and produces a desirable effect, there is a good chance that they may play better because they are more comfortable and confident.

<u>Future Work</u>

Experiments Possible with Collected Data

With the volume of data collected in this experiment, extensive future analysis is possible. As a performer, I was able to perform limited statistical analyses, but a researcher with more statistics experience could conduct multi-level data analysis, which could help identify any acoustic differences between the stoppers by using every listener score rather than averaging each listener's score for each stopper. This multilevel modeling approach could examine three levels of variables simultaneously: listener perception, player perception, and stopper output. This could be a method used to determine player preference or "fit."

Experiments on "Fit"

Based on the statistical analysis, listeners perceived no consistent, discernable differences between the stoppers, but the players "fit" (or performer preference) scores were drastically different. Because the stoppers had a significant effect on player preference, I believe playing on a stopper which is a good "fit" becomes even more important.

Based on my own experience and the player's perception test feedback, I would define a stopper with a good "fit" as a stopper that produces:

1. Expected and preferable aural qualities (tone, timbre, dynamics, projection, etc.)
2. Expected and preferable tactile qualities (response, regardless of dynamics, register, and articulation)
3. Ease of execution of the qualities above

I would like to see further experiments conducted on "fit," because it would be helpful to determine if the players' responses are consistent. If stoppers have a statistically significant effect on "fit," it would be helpful to determine which stopper designs and materials work best for different kinds of players and different headjoint cuts. I understand that it will always be necessary to engage in some trial and error when choosing a new stopper, but research has already made an impact on the choices we make. We now understand a great deal about beveling the embouchure hole and effects of the chimney design, which makes it easier to find a headjoint that fits. I believe the same research can be done on flute stoppers, to help narrow down the kind of stoppers flutists should try, or to guide them toward the right setup on a customizable stopper.

WORKS CITED

Adobe Systems, Adobe Audition, Version 13.0.5.36. Computer program. Accessed March 24, 2020. https://www.adobe.com/products/audition.html.

Atema, Jelle. "Musical Origins and the Stone Age Evolution of Flutes." *Acoustics Today* 10, no. 3 (Summer 2014): 26-34. https://acousticstoday.org/wp-content/uploads/2015/05/Musical-Origins-and-the-Stone-Age-Evolution-of-Flutes.pdf.

———. "Science Association Conference: Neanderthal Man Played the Recorder." *The Independent*, February 21, 2000. Accessed March 24, 2020. http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/311603674?accountid=4485.

Backus, John. "Effect of Wall Material on the Steady-State Tone Quality of Woodwind Instruments." *The Journal of the Acoustical Society of America* 36, no. 10 (October 1964): 1881-1887. Accessed on March 24, 2020. https://doi.org/10.1121/1.1919286.

Banks, Sally. "Sweet Sounds Waft from Fipple Flutes." *Calgary Herald*, March 15, 1992. Accessed March 24, 2020. http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/244162997?accountid=4485.

Bigio, Robert. "Stoppers and Crowns." Accessed March 24, 2020. http://www.bigio.com/stoppersandcrowns.htm.

Boehm, Theobald. *The Flute and Flute-Playing in Acoustical, Technical, and Artistic Aspects* (1871). Translated by Dayton C. Miller. New York: Dover, 1964.

Boersma, Paul and David Weenink. Praat: Doing Phonetics by Computer, Version 6.0.37. Computer program. Accessed March 24, 2020. http://www.praat.org/.

Briccialdi Flutes Italy. "Briccialdi Titanium Stopper Plug." Accessed March 24, 2020. https://www.briccialdi.it/.

Brodeur, Amelie. "Flutealot's Swap Stopper System Kit." YouTube video. Posted on February 21, 2018, and accessed March 24, 2020. https://www.youtube.com/watch?v=tEeebmOA2ZQ.

CE Flute. "Stoppers." Accessed March 24, 2020. http://www.ce-flute.eu/en/stoppers/.

Cluff, Jennifer. "Raymond Robinson Tests Flute Crowns and Stoppers by Robert Bigio and DynaSystems." Sound file. Flute Loops 8 (2007). Accessed March 24, 2020. https://www.jennifercluff.com/fluteloops08.htm.

Coltman, John W. "Effect of Material on Flute Tone Quality." *The Journal of the Acoustical Society of America* 49, no. 2 (1971): 520-523. Accessed on March 24, 2020. https://doi.org/10.1121/1.1912381.

Dickens, Paul A. "Flute Acoustics: Measurement, Modelling, and Design." PhD diss., University of New South Wales, 2007.

Fairley, Andrew. *Flutes, Flautists and Makers: Active or Born Before 1900*. London: Pan Educational Music, 1982.

Feliciano, Roberto. Flute Head Joint Stopper. U.S Patent 8,669,449, filed June 11, 2012, and issued March 11, 2014. Accessed on March 24, 2020. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=8,669,449.PN.&OS=PN/8,669,449&RS=PN/8,669,449.

———. "Part 2-3: Rhino Flute Resonator One Ring or Two Ring and Accessories." YouTube video. Posted on November 2, 2016. Accessed on March 24, 2020. https://youtu.be/vHxWwrMjg-4.

———. "RFRolon." YouTube Channel. Founded on November 28, 2007, and accessed March 24, 2020. https://www.youtube.com/user/rfrolon.

Ferron, Ernest. Obturator for Flute Designed to Improve the Emission of Certain Notes. US Patent 4,499,810, filed June 21, 1983, issued February 19, 1985, and expired on June 21, 2003. Accessed on March 24, 2020. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4,499,810.PN.&OS=PN/4,499,810&RS=PN/4,499,810.

Fitzgibbon, Macaulay. *The Story of the Flute*. New York: William Reeves, Bkseller, ltd., 1914.

Gardner, Joshua. "Effects of a Synthetic Clarinet Bore Liner on Spectral Centroid and Fundamental Frequency Error." *Acta Acoustica* 105, no. 6 (December 2019): 1206-1216. Accessed on March 24, 2020. https://doi.org/10.3813/AAA.919397.

Hardy, Christina. "Instrument of the Spirits." *The Nelson Mail*, October 12, 2013. Accessed March 24, 2020. https://search-proquest-com.ezproxy1.lib.asu.edu/docview/1441442712/CF6971AC2D1B412EPQ/2?accountid=4485.

Hoeckley, Stephanie. "Flute Stopper Mechanism." Photo. April 24, 2020.

Holbrook, Allyson. "Acquiescence Response Bias." *Encyclopedia of Survey Research Methods*, edited by Paul A. Lavrakas. Thousand Oaks: SAGE Publishing, 2011. Accessed on March 24, 2020. https://dx.doi.org/10.4135/9781412963947.n3.

Kalkandjiev, Zora Schärer and Stefan Weinzierl. "The Influence of Room Acoustics." *Psychomusicology: Music, Mind, and Brain* 25, no. 3 (2015): 195-207. Accessed on March 24, 2020. http://dx.doi.org/10.1037/pmu0000065.

Leithold, Paul. "Performance Flute Plug Installation Guide." YouTube video. Posted on January 14, 2015, and accessed March 24, 2020. https://www.youtube.com/watch?v=NkKfR8B5T28.

Leung, Cleo. "Overtone Characterization of Garner Headjoints Using Spectrographic Analysis and Fast Fourier Transforms." DMA diss., University of Cincinnati College-Conservatory of Music, 2011. Accessed on March 24, 2020. http://rave.ohiolink.edu/etdc/view?acc_num=ucin1396523100.

Lewis, Gary. "Flute Crown Assemblies." Last modified 2016. Accessed March 24, 2020. http://www.garylewisflutes.com/index.php?main_page=index&cPath=16.

———. Headjoint Crown Assembly with Extension Unit. US Patent 8,653,347, filed August 10, 2012, and issued February 18, 2014. Accessed on March 24, 2020. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=8,653,347.PN.&OS=PN/8,653,347&RS=PN/8,653,347.

Linortner, Renate. "Silver, Gold, and Platinum: Wall Material and the Sound of the Flute." Thesis excerpt. PhD diss., University of Music and Performing Arts Vienna, Institute of Music Acoustics, 2001. Accessed on March 24, 2020. http://iwk.mdw.ac.at/?page_id=97&sprache=2.

Maclagen, Susan. *Dictionary for the Modern Flutist.* Lanham, MD: Scarecrow, 2009.

Mahaut, Antoine. *A New Method for Learning to Play the Transverse Flute.* Bloomington: Indiana University Press, 1989.

McGee Flutes. "Effect of Stopper Position." Accessed March 24, 2020. http://www.mcgee-flutes.com/Stopper.html.

Mendelssohn, Felix. *Midsummer Night's Dream, Op. 61.* Leipzig: Breitkopf und Härtel, 1842.

Moyse, Marcel. *24 Little Melodic Studies*. Paris: Alphonse Leduc, 1932.

Murphy, Enda and Eoin A. King. "Principles of Environmental Noise." *Environmental Noise Pollution.* Elsevier, 2014. Accessed on March 24, 2020. https://doi.org/10.1016/C2012-0-13587-0.

Narodni Muzej Slovenije. "Neanderthal Flute." Accessed on April 20, 2020. https://www.nms.si/en/collections/highlights/343-Neanderthal-flute.

"New Products," *Flutist Quarterly* 37, no. 1 (Fall 2011): 64-66. Accessed on March 24, 2020. http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/902666361?accountid=4485.

Parmenon, Michel. Flute. US Patent 2007/0272071A1, filed September 2, 2004, application published November 29, 2007, and application abandoned. Accessed on March 24, 2020. https://patents.google.com/patent/US20070272071A1/en?q=flute&inventor=parmenon&oq=parmenon+flute.

Pellerite, James. Headjoint Stopper. US Patent 4,240,320, filed March 21, 1980, issued December 23, 1980, and expired November 27, 1998. Accessed on March 24, 2020. http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4,240,320.PN.&OS=PN/4,240,320&RS=PN/4,240,320.

Phelan, James. *The Complete Guide to the Flute and Piccolo*. 2nd ed. Acton, MA: Burkart-Phelan, 2000.

Quantz, Joachim. *On Playing the Flute.* New York: Schirmer Books, 1966.

RFRolon, "Celestine Flute Rexonator." Accessed March 24, 2020. https://www.rfrolon.com/product/celestine-flute-rexonator-balance.

— — —. Variable Flute Stopper. United Kingdom Patent GB2544047A, filed November 2, 2015, application published May 10, 2017, and application pending. Accessed on March 24, 2020. https://patents.google.com/patent/GB2544047A/en?q=variable+flute+stopper&oq=variable+flute+stopper.

Rockstro, Richard Shepherd. *A Treatise on the Construction, the History, and the Practice of the Flute* (1928). 2nd ed. Translated by Georgina M. Rockstro. London: Musica Rara, 1967.

Rucz, Péter. "Acoustical Evaluation of a Novel Flute Head Construction Acoustical Evaluation of a Novel Flute Head Construction." Conference Paper presented at the 44th German Annual Conference on Acoustics, München, Germany, March 19-22, 2018. Accessed on March 24, 2020. https://www.researchgate.net/publication/324909919_Acoustical_evaluation_of_a_novel_flute_head_construction.

Schubert, Emery and Joe Wolfe. "Does Timbral Brightness Scale with Frequency and Spectral Centroid?." *Acta Acustica* 92, no. 5 (June 2006): 820-825. Accessed on March 24, 2020. https://newt.phys.unsw.edu.au/~jw/reprints/SchubertWolfe06.pdf.

Seidman, Mark. Acoustically Pleasing Headjoint Stopper for a Transverse Flute. US Patent US2010/0018380A1, filed July 23, 2008, application published January 28, 2010, and application abandoned. Accessed on March 24, 2020. https://patents.google.com/patent/US20100018380A1/en?q=Acoustically+Pleasing+Headjoint+Stopper+Transverse+Flute&oq=Acoustically+Pleasing+Headjoint+Stopper+for+a+Transverse+Flute.

Seidman Flute Technology. "Feedback/Reviews." Accessed March 24, 2020. http://www.seidmanflutetechnology.com/feedbackreviews.html.

Symington, David. "Stopper Sounds." *Pan: The Flute Magazine* 22, no. 1 (March 2003).

Tait, Jasmine. "A Comparison of Acoustic Effects of Two Stopper and Crown Systems in the Modern Flute." *Canadian Acoustics* 29, no. 4 (December 2001): 40-44. Accessed March 24, 2020. http://jcaa.caa-aca.ca/index.php/jcaa/article/viewFile/1421/1165.

The Metropolitan Museum of Art. "Flute Stopper." Accessed March 24, 2020. https://www.metmuseum.org/art/collection/search/313775.

Toff, Nancy. *The Development of the Modern Flute.* 1st ed. Champaign, IL: University of Illinios, 1986.

———. *The Flute Book: A Complete Guide for Students and Performers*. 2nd ed. Oxford: Oxford University, 1996.

Tromlitz, Johann. *The Keyed Flute*. New York: Oxford University Press, 1996.

White, Joan. "A Spectral Analysis of the Tones of Five Flutes Constructed of Different Materials." Ed.D diss., The University of North Carolina at Greensboro, 1980. Accessed on March 24, 2020. http://login.ezproxy1.lib.asu.edu/login?url=https://search-proquest-com.ezproxy1.lib.asu.edu/docview/303037716?accountid=4485.

———. "Flute Tone Quality: Does the Metal Make a Difference?." *Flute Talk Journal* 8 (1989): 34-35.

Wilson, Rick. "19th Century Boehm Flutes." Accessed March 24, 2020. http://www.oldflutes.com/boehm.htm.

Woodwind Music. "Robert Bigio Zirconium Stoppers and Crown." Accessed March 24, 2020. http://www.woodwind.dk/Bigio%20stoppers.htm.

Wolfe, Joel, John Smith, and Michael Green. "The Effects of the Placement of the Head Joint Stopper on the Impedance Spectra of Transverse Flutes." Conference Paper presented at the Eighth Western Pacific Acoustics Conference, Melbourne, Australia, April 7-9, 2003. Accessed on March 24, 2020. https://newt.phys.unsw.edu.au/jw/reprints/stoppers.pdf.

Yamauchi, Katsuya, Yasunao Kai, and Shin-ichiro Iwamiya. "The Effects of Materials of a Flute's Crown and a Cello's Endpin on the Timbre of Musical Instruments." *Acoustical Science and Technology* 22, no. 1 (2001): 47-48. Accessed March 24, 2020. https://doi.org/10.1250/ast.22.47.

Young, Corinth D. and Diane Boyd Schultz. "Effects of Head Joint Material and Instrument Manufacturer on Flute Timbre, as Measured by the Intensity of the First Nine Overtones in the Harmonic Series." *The University of Alabama McNair Journal,* 139-154. Accessed on March 24, 2020. http://www.shmuelyosef.com/Saxophones/Flute/Articles/Effects%20of%20Head%20Joint%20Material%20and%20Instrument%20Manufacturer%20on%20Flute%20Timbre.pdf.

APPENDIX A

GENERAL STOPPER USAGE SURVEY

GENERAL STOPPER USAGE SURVEY

Acoustic and Perceived Effects of the Flute's Stopper Mechanism

You are invited to participate in a web-based online survey on the use of flute stoppers. The stopper seals the top end of the flute's headjoint, and is traditionally made of cork. However, there are also many non-cork stoppers available. If you play a C flute, we would like to know more about the stopper you use. (New flutes come with cork stoppers.)

This is a research project being conducted by Stephanie Hoeckley, a Doctorate of Musical Arts student at Arizona State University. Ultimately, this survey is part of a larger project that will study the acoustic and perceived effects of different stopper mechanisms in C flutes. The survey should take approximately 5 minutes to complete.

Participation
Your participation in this survey is voluntary. You may refuse to take part in the research or exit the survey at any time without penalty. You are free to decline to answer any particular question you do not wish to answer for any reason.

Confidentiality
Your survey answers will be sent to a link at Qualtrics.com where the data will be stored in a password protected electronic format. Qualtrics does not collect identifying information such as your name, email address, or IP address. Therefore, your responses will remain anonymous. No one will be able to identify you or your answers, and no one will know whether or not you participated in the study.

Contact
If you have any questions concerning the research study, please contact me at Stephanie.Hoeckley@asu.edu or contact the Primary Investigator at Elizabeth.Buck.1@asu.edu.

If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.

Electronic Consent
You may print a copy of this consent form for your records. By selecting the choice "I consent" for question #1, you are confirming that:

- You have read the above information
- You voluntarily agree to participate
- You are 18 years of age or older

All participants:

1. In which country do you currently reside?
   [Select from the dropdown options]

2. What is your age?
   a. 18-24
   b. 25-34
   c. 35-44
   d. 45-54
   e. 55-64
   f. 65-74
   g. 85 or older

3. How long have you played the flute?
   a. Less than 1 year
   b. 1-4 years
   c. 5-10 years
   d. 10-20 years
   e. 20+ years

4. Which kind of flutist do you consider yourself?
   a. Professional: A flute-related job(s) is my primary source of income
   b. Amateur: I studied music in college, but a non-flute job is my primary source of income
   c. Hobbyist: I play the flute as a hobby (I have never studied flute in college, and a non-flute job is my primary source of income)
   d. Student: I am currently pursuing a flute-related degree in college
   e. Other: Please describe _________

Participants who indicated that they have or are currently pursuing a degree:

5. What is the highest level of education you have completed?
   a. High School Diploma
   b. Bachelor's
   c. Master's
   d. Post-Graduate
   e.
6. What is the major of your highest level degree?
   a. Flute Performance
   b. Music Education
   c. Music Therapy
   d. Other, please list: _________

All participants:

7. New flutes are sold with stoppers made out of cork. Which of the following NON-cork stoppers have you heard of? Please select all that apply.

a. Bigio Stopper
b. Briccialdi Titanium Stopper Plug
c. Celestine Rexonator/Rhino Resonator
d. Dyna Flute System
e. Gary Lewis Select Crown Assembly
f. Seidman Flute Stopper Plug
g. Swap-Stopper
h. Symington "Flutemet"
i. Other, please list: _________

8. Do you currently play or perform on a stopper that did not originally come with your flute (AKA a non-cork stopper)?
    a. Yes, I play on a non-cork stopper
    b. No, I play on a cork stopper

Participants who indicated that they currently play on a non-cork stopper:

9. Which non-cork flute stopper do you use? Please list the brand and material.
    a. Stopper brand: _________
    b. Stopper material: _________

10. I can play with improved projection (loudness) with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

11. I can produce a softer sound with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

12. I can produce a more stable tone while playing at a soft dynamic with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

13. Timbre: A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics.
    I produce a bright sound with my non-cork stopper.

a. Strongly agree
b. Somewhat agree
c. Neither agree nor disagree
d. Somewhat disagree
e. Strongly disagree

14. I produce a more focused tone with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

15. I produce a more ideal tone quality with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

16. I produce a more ideal tone quality in all registers with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

17. I produce clearer articulation with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

18. Do you change your stopper in various musical situations? For example, do you use one stopper in one situation and another stopper in another? If yes, please explain.
    a. Yes: Please explain: _________
    b. No

19. Do you have any other thoughts or feedback on stoppers and/or how you use them that you would like to share?

Participants who indicated that they currently perform on a cork stopper:

20. Please select the following statement that most matches your experience with non-cork stoppers.
    a. I own a non-cork stopper but no longer use it.
    b. I have tried a non-cork stopper before but have never owned one.
    c. I have never tried nor owned a non-cork stopper.

21. If there were published studies about the effects of non-cork stoppers, would you consider using one?
    a. Yes, I would consider using a non-cork stopper.
    b. No, I would not consider using a non-cork stopper.

22. Do you have any other thoughts or feedback on stoppers and/or how you use them that you would like to share? _________

Participants who indicated that they have tried or owned a non-cork stopper:

23. Which stopper(s) have you tried or owned? Please list the brand and material.
    a. Stopper brand: _________
    b. Stopper material: _________

24. I could play with improved projection (loudness) with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

25. I produced a softer sound with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

26. I can produce a more stable tone while playing at a soft dynamic with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

27. Timbre: A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics.
    I produced a bright sound with my non-cork stopper.

a. Strongly agree
b. Somewhat agree
c. Neither agree nor disagree
d. Somewhat disagree
e. Strongly disagree

28. I could produce a more focused tone with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

29. I could produce a more ideal tone quality with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

30. I could produce a more ideal tone quality in all registers with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

31. I could produce clearer articulation with my non-cork stopper.
    a. Strongly agree
    b. Somewhat agree
    c. Neither agree nor disagree
    d. Somewhat disagree
    e. Strongly disagree

32. Do you change your stopper in various musical situations? For example, do you use one stopper in one situation and another stopper in another? If yes, please explain.
    a. Yes: Please explain: _________
    b. No
33. Do you have any other thoughts or feedback on stoppers and/or how you use them that you would like to share? _________

END OF SURVEY

APPENDIX B

PLAYER PERCEPTION TEST

PLAYER PERCEPTION TEST

Acoustic and Perceived Effects of the Flute's Stopper Mechanism

I am a Doctorate of Musical Arts student under the direction of Dr. Elizabeth Buck in the School of Music in the Herberger School for Design and the Arts at Arizona State University. I am conducting a research study to determine the acoustic and perceived effect of different stopper mechanisms in C flutes. Specifically, I hope to determine how these stoppers affect resonance, volume, clarity of articulation, and the player's perceived "fit," or how well they feel the stopper suits their playing style and desired sound.

I am inviting your participation, which will involve playing and audio recording short musical examples (called the "playing test") while using 5 different flute stoppers in 2 different venues. The playing test will be performed on the test flute, so there is no risk to your instrument. The first recording session will take place at Clarke Rigsby's Tempest Recording Studio and the second recording session will take place in ASU's Katzin Concert Hall. Both will take about 45 minutes for a maximum of 1.5 hours. There will be a few written questions to answer about your perceived opinion of each stopper before switching to the next stopper. A listening panel will listen to and evaluate the randomized recordings from the second recording day with a similar survey.

I will audio record the playing tests in both venues. The playing test will not be recorded without your permission. Please let me know if you do not want the test to be recorded; you also can change your mind after the test starts. Your recordings and responses will be anonymous, and your name will not be attached to the data. Your data will be labelled as "Player A," Player B," etc. The results of this study may be used in reports, presentations, or publications but your name will not be used.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty and your relationship with the research team will not be affected. You have the right not to answer any question, and to stop participation at any time. You must be 18 or older to participate in the study.

The data I will collect will help de-mystify the effects of the flute stopper, which makers agree that they do not wholly understand. Although there is no guaranteed benefit to you, is possible that throughout the process of playing with different stoppers that you might find one that "fits" you well. Because it can be helpful to hear how you sound on a different flute "setup" before purchasing, your recordings and the analysis of your recorded data is available at your request.

If you have any questions concerning the research study, please contact the research team at Stephanie.Hoeckley@asu.edu and Elizabeth.Buck.1@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.

By signing below you are agreeing to be part of the study.

Name:

Signature: Date:

Acoustic and Perceived Effects of the Flute's Stopper Mechanism

Player #: _____________

Performer Survey for Stopper #1

Please rate your opinion of each stopper on a scale of 1-5, 1 being "strongly disagree" and 5 being "strongly agree."

Please answer the following questions after you perform on each stopper:

1. The overall tone quality of this stopper is resonant and ideal.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

2. This stopper produces a consistently ideal and resonant tone quality in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

3. This stopper produces a bright sound.
    1 – Strongly disagree, it is a dark sound.
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree, it is a bright sound.

4. This stopper produces good projection (loudness) overall.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

5. This stopper produces good projection (loudness) in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree
6. This stopper allows clear articulation overall.

1 – Strongly disagree
2 – Somewhat disagree
3 – Neither agree nor disagree
4 – Somewhat agree
5 – Strongly agree

7. This stopper allows clear articulation in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

8. I feel that this stopper is a good "fit" for me. It feels comfortable to play and produces the effects I expect and prefer.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

9. After all stoppers have been tested, please list your favorite stopper(s) here, if applicable.

____

10. Please list any additional comments you have below.

____

____

Performer Survey for Stopper #2

Please rate your opinion of each stopper on a scale of 1-5, 1 being "strongly disagree" and 5 being "strongly agree."

Please answer the following questions after you perform on each stopper:

1. The overall tone quality of this stopper is resonant and ideal.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree
2. This stopper produces a consistently ideal and resonant tone quality in all registers.

1 – Strongly disagree
2 – Somewhat disagree
3 – Neither agree nor disagree
4 – Somewhat agree
5 – Strongly agree

3. This stopper produces a bright sound.
    1 – Strongly disagree, it is a dark sound.
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree, it is a bright sound.

4. This stopper produces good projection (loudness) overall.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

5. This stopper produces good projection (loudness) in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

6. This stopper allows clear articulation overall.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

7. This stopper allows clear articulation in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

8. I feel that this stopper is a good "fit" for me. It feels comfortable to play and produces the effects I expect and prefer.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree

5 – Strongly agree

9. After all stoppers have been tested, please list your favorite stopper(s) here, if applicable.

____

10. Please list any additional comments you have below.

____

____

Performer Survey for Stopper #3

Please rate your opinion of each stopper on a scale of 1-5, 1 being "strongly disagree" and 5 being "strongly agree."

Please answer the following questions after you perform on each stopper:

1. The overall tone quality of this stopper is resonant and ideal.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

2. This stopper produces a consistently ideal and resonant tone quality in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

3. This stopper produces a bright sound.
    1 – Strongly disagree, it is a dark sound.
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree, it is a bright sound.

4. This stopper produces good projection (loudness) overall.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree

5 – Strongly agree

5. This stopper produces good projection (loudness) in all registers.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

6. This stopper allows clear articulation overall.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

7. This stopper allows clear articulation in all registers.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

8. I feel that this stopper is a good "fit" for me. It feels comfortable to play and produces the effects I expect and prefer.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

9. After all stoppers have been tested, please list your favorite stopper(s) here, if applicable.

____

10. Please list any additional comments you have below.

____

____

Performer Survey for Stopper #4

Please rate your opinion of each stopper on a scale of 1-5, 1 being "strongly disagree" and 5 being "strongly agree."

Please answer the following questions after you perform on each stopper:

1. The overall tone quality of this stopper is resonant and ideal.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

2. This stopper produces a consistently ideal and resonant tone quality in all registers.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

3. This stopper produces a bright sound.
   1 – Strongly disagree, it is a dark sound.
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree, it is a bright sound.

4. This stopper produces good projection (loudness) overall.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

5. This stopper produces good projection (loudness) in all registers.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

6. This stopper allows clear articulation overall.
   1 – Strongly disagree
   2 – Somewhat disagree
   3 – Neither agree nor disagree
   4 – Somewhat agree
   5 – Strongly agree

7. This stopper allows clear articulation in all registers.
   1 – Strongly disagree

2 – Somewhat disagree
3 – Neither agree nor disagree
4 – Somewhat agree
5 – Strongly agree

8. I feel that this stopper is a good "fit" for me. It feels comfortable to play and produces the effects I expect and prefer.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

9. After all stoppers have been tested, please list your favorite stopper(s) here, if applicable.

____

10. Please list any additional comments you have below.

____

____

Performer Survey for Stopper #5

Please rate your opinion of each stopper on a scale of 1-5, 1 being "strongly disagree" and 5 being "strongly agree."

Please answer the following questions after you perform on each stopper:

1. The overall tone quality of this stopper is resonant and ideal.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

2. This stopper produces a consistently ideal and resonant tone quality in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

3. This stopper produces a bright sound.

1 – Strongly disagree, it is a dark sound.
2 – Somewhat disagree
3 – Neither agree nor disagree
4 – Somewhat agree
5 – Strongly agree, it is a bright sound.

4. This stopper produces good projection (loudness) overall.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

5. This stopper produces good projection (loudness) in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

6. This stopper allows clear articulation overall.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

7. This stopper allows clear articulation in all registers.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

8. I feel that this stopper is a good "fit" for me. It feels comfortable to play and produces the effects I expect and prefer.
    1 – Strongly disagree
    2 – Somewhat disagree
    3 – Neither agree nor disagree
    4 – Somewhat agree
    5 – Strongly agree

9. After all stoppers have been tested, please list your favorite stopper(s) here, if applicable.

____

10. Please list any additional comments you have below.

APPENDIX C

LISTENER PERCEPTION TEST

LISTENER PERCEPTION TEST

Acoustic and Perceived Effects of the Flute's Stopper Mechanism

I am a Doctorate of Musical Arts student under the direction of Dr. Elizabeth Buck in the School of Music in the Herberger School for Design and the Arts at Arizona State University. I am conducting a research study to study the acoustic and perceived effects of different stopper mechanisms in C flutes.

I am inviting your participation, which will involve listening to 4 different flutists test 5 stoppers in ASU's Recital Hall. You will be asked to answer a few questions about your perceived opinion of each stopper's characteristics, such as tone quality, brightness, loudness, focus, and clarity of articulation. Each of the 2 perception tests will take about 50 minutes and will be scheduled on 2 separate days.

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty and your relationship with the research team will not be affected. You have the right not to answer any question, and to stop participation at any time. You must be 18 or older to participate in the study.

Your responses will be anonymous, and your name will not be attached to the data. Your data will be labelled as "listener 1," "listener 2," etc. The results of this study may be used in reports, presentations, or publications but your name will not be used.

If you have any questions concerning the research study, please contact the research team at Stephanie.Hoeckley@asu.edu and Elizabeth.Buck.1@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be part of the study.

By signing below you are agreeing to be part of the study.

Name:

Signature: Date:

Stopper Perception Test

Age: ____ # of Years Playing Flute: ____ Degree Program + Year: _________

Listener Survey for Player A, Stopper #1

Please rank your opinion of each characteristic by circling your choice on a scale of 1-5.

Crescendo to Maximum and Fortissimo Chromatic Scale:

1. This stopper produces good projection (loudness) overall.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Projection is poor) (Sound projects well)

Decrescendo to Minimum and Pianissimo Chromatic Scale:

2. This stopper can effectively produce a soft sound overall.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Does not play softly) (Can play softly)

3. This stopper produces a stable piano dynamic.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Piano is unstable) (Piano is stable)

Moyse Tone Example:

4. A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics. [The preceding sentence was not present in Listening Perception Test 1, only Listening Perception Test 2]

   This stopper produces a bright sound.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is dark) (Sound is bright)

5. This stopper produces a focused sound.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is fluffy or airy) (Sound is focused)

6. The overall tone quality of this stopper is resonant and ideal.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not ideal) (Tone is ideal)

7. This stopper produces a consistently ideal and resonant tone quality in all registers.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not consistent) (Tone is consistent)

Mendelssohn Scherzo Excerpt:

8. This stopper allows for clear articulation overall.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Articulation is unclear) (Articulation is clear)

Additional Note Space:

Listener Survey for Player A, Stopper #2

Please rank your opinion of each characteristic by circling your choice on a scale of 1-5.

Crescendo to Maximum and Fortissimo Chromatic Scale:

1. This stopper produces good projection (loudness) overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Projection is poor) (Sound projects well)

Decrescendo to Minimum and Pianissimo Chromatic Scale:

2. This stopper can effectively produce a soft sound overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Does not play softly) (Can play softly)

3. This stopper produces a stable piano dynamic.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Piano is unstable) (Piano is stable)

Moyse Tone Example:

4. A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics. [The preceding sentence was not present in Listening Perception Test 1, only Listening Perception Test 2]

This stopper produces a bright sound.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is dark) (Sound is bright)

5. This stopper produces a focused sound.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is fluffy or airy) (Sound is focused)

6. The overall tone quality of this stopper is resonant and ideal.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not ideal) (Tone is ideal)

7. This stopper produces a consistently ideal and resonant tone quality in all registers.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not consistent) (Tone is consistent)

Mendelssohn Scherzo Excerpt:

8. This stopper allows for clear articulation overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Articulation is unclear) (Articulation is clear)

Additional Note Space:

Listener Survey for Player A, Stopper #3

Please rank your opinion of each characteristic by circling your choice on a scale of 1-5.

Crescendo to Maximum and Fortissimo Chromatic Scale:

1. This stopper produces good projection (loudness) overall

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Projection is poor) (Sound projects well)

Decrescendo to Minimum and Pianissimo Chromatic Scale:

2. This stopper can effectively produce a soft sound overall.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Does not play softly) (Can play softly)

3. This stopper produces a stable piano dynamic.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Piano is unstable) (Piano is stable)

Moyse Tone Example:

4. A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics. [The preceding sentence was not present in Listening Perception Test 1, only Listening Perception Test 2]

This stopper produces a bright sound.

1	2	3	4	5
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is dark) (Sound is bright)

5. This stopper produces a focused sound.

1----------------------2	---------------------3	--------------------4	--------------------5	
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is fluffy or airy) (Sound is focused)

6. The overall tone quality of this stopper is resonant and ideal.

1----------------------2	---------------------3	--------------------4	--------------------5	
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not ideal) (Tone is ideal)

7. This stopper produces a consistently ideal and resonant tone quality in all registers.

1----------------------2	---------------------3	--------------------4	--------------------5	
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not consistent) (Tone is consistent)

Mendelssohn Scherzo Excerpt:

8. This stopper allows for clear articulation overall.

1----------------------2	---------------------3	--------------------4	--------------------5	
Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Articulation is unclear) (Articulation is clear)

Additional Note Space:

Listener Survey for Player A, Stopper #4

Please rank your opinion of each characteristic by circling your choice on a scale of 1-5.

Crescendo to Maximum and Fortissimo Chromatic Scale:

1. This stopper produces good projection (loudness) overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Projection is poor) (Sound projects well)

Decrescendo to Minimum and Pianissimo Chromatic Scale:

2. This stopper can effectively produce a soft sound overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Does not play softly) (Can play softly)

3. This stopper produces a stable piano dynamic.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Piano is unstable) (Piano is stable)

Moyse Tone Example:

4. A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics. [The preceding sentence was not present in Listening Perception Test 1, only Listening Perception Test 2]

This stopper produces a bright sound.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is dark) (Sound is bright)

5. This stopper produces a focused sound.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is fluffy or airy) (Sound is focused)

6. The overall tone quality of this stopper is resonant and ideal.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not ideal) (Tone is ideal)

7. This stopper produces a consistently ideal and resonant tone quality in all registers.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not consistent) (Tone is consistent)

Mendelssohn Scherzo Excerpt:

8. This stopper allows for clear articulation overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Articulation is unclear) (Articulation is clear)

Additional Note Space:

Listener Survey for Player A, Stopper #5

Please rank your opinion of each characteristic by circling your choice on a scale of 1-5.

Crescendo to Maximum and Fortissimo Chromatic Scale:

1. This stopper produces good projection (loudness) overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Projection is poor) (Sound projects well)

Decrescendo to Minimum and Pianissimo Chromatic Scale:

2. This stopper can effectively produce a soft sound overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Does not play softly) (Can play softly)

3. This stopper produces a stable piano dynamic.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Piano is unstable) (Piano is stable)

Moyse Tone Example:

4. A bright sound has more higher harmonics present in the sound. A dark sound has fewer high harmonics. [The preceding sentence was not present in Listening Perception Test 1, only Listening Perception Test 2]

   This stopper produces a bright sound.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is dark) (Sound is bright)

5. This stopper produces a focused sound.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Sound is fluffy or airy) (Sound is focused)

6. The overall tone quality of this stopper is resonant and ideal.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not ideal) (Tone is ideal)

7. This stopper produces a consistently ideal and resonant tone quality in all registers.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Tone is not consistent) (Tone is consistent)

Mendelssohn Scherzo Excerpt:

8. This stopper allows for clear articulation overall.

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

Strongly Disagree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree

(Articulation is unclear) (Articulation is clear)

Conclusion:

9. After all stoppers have been tested for this player, please rank the stoppers from 1 to 5, from your favorite to least favorite.
   (1 being your favorite, 5 being your least favorite)

________	________	________	________	________
Stopper #1	Stopper #2	Stopper #3	Stopper #4	Stopper #5

[Above questions repeated identically for Players B, C, and D]

END OF SURVEY

APPENDIX D

RECRUITMENT SCRIPTS

RECRUITMENT SCRIPTS

Player Participants

I am a Doctorate of Musical Arts student under the direction of Dr. Elizabeth Buck in the School of Music in the Herberger School for Design and the Arts at Arizona State University. I am conducting a research study to study the acoustic and perceived effect of different stopper mechanisms in modern-day Boehm flutes. Specifically, I hope to determine how these stoppers affect resonance, volume, clarity of articulation, and the player's perceived "fit," or how well they feel the stopper suits their playing style and desired sound.

I am recruiting individuals to play and audio record short musical examples (called the "playing test") while using different flute stoppers in two different venues. The first recording session will take place at a recording space in Tempe and will last about an hour. The second recording session will take place at Arizona State University and will last about 45 minutes. There will be a few questions to answer about your perceived opinion of each stopper before switching to the next stopper for each recording session. The two recording sessions will likely be on two separate days and each will be scheduled at the participant's convenience.

The study will take approximately 45-60 minutes on two separate days (1 hour and 45 minutes total). Your participation in this study is voluntary. If you have any questions concerning the research study, please email stephanie.hoeckley@asu.edu or call (407) 491-6767.

Listener Participants

I am a Doctorate of Musical Arts student under the direction of Dr. Elizabeth Buck in the School of Music in the Herberger School for Design and the Arts at Arizona State University. I am conducting a research study to study the acoustic and perceived effect of different stopper mechanisms in modern-day Boehm flutes. Specifically, I hope to determine how these stoppers affect resonance, volume, clarity of articulation, and the player's perceived "fit," or how well they feel the stopper suits their playing style and desired sound.

I am recruiting individuals to listen to four flutists perform on the different stoppers being tested. The experiment will take place in ASU's Recital Hall and will take approximately 50 minutes on two separate days. You will be part of a designated listening panel that will be asked to answer questions on how flutists perceive the stopper's resonance, volume, and clarity of articulation.

Your participation in this study is voluntary. If you have any questions concerning the research study, please call me at (407) 491-6767.

Online Social Media General Stopper Usage Survey Participants

Hi everyone! I am writing my dissertation on the acoustic and perceived effects of the flute's stopper. It's been a topic of immense curiosity for me for quite some time now, and I hope you can help me with my research!

If you play the C flute, please consider filling out my short survey about the flute stopper you use (cork or otherwise). You can help me determine how flutists use the many different kinds of stoppers available today. (The stopper is what seals the upper end of the headjoint, and it is traditionally made of cork, although they can be made of many different materials.)

This survey is part of a larger research project at Arizona State University that will determine the acoustic and perceived effects of the flute's stopper. In the survey, you will be asked to answer some questions about which kind of flute stopper(s) you use. It should take about 5 minutes and will be available until March 1, 2020.

If interested, please access the survey at the link below. Thank you so much!

Survey link: https://asu.co1.qualtrics.com/jfe/form/SV_e9xf8Cgia2eEP0V

APPENDIX E

INSTITUTIONAL REVIEW BOARD EXEMPTION

INSTITUTIONAL REVIEW BOARD EXEMPTION

ASU Knowledge Enterprise Development

APPROVAL: EXPEDITED REVIEW

Elizabeth Buck
HIDA: Music, School of
480/965-3540
Elizabeth.Buck.1@asu.edu

Dear Elizabeth Buck:

On 5/6/2019 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Acoustic and Perceived Effects of Stopper Mechanisms in Modern-Day Boehm Flutes
Investigator:	Elizabeth Buck
IRB ID:	STUDY00010125
Category of review:	(6) Voice, video, digital, or image recordings, (7)(b) Social science methods, (7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Listener Consent Form.pdf, Category: Consent Form; • General Survey Questions, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Performer Consent Form.pdf, Category: Consent Form; • General Survey Consent Form.pdf, Category: Consent Form; • Hoeckley Social-Behavioral Protocol Form.docx, Category: IRB Protocol; • Recruitment Scripts.pdf, Category: Recruitment Materials;

The IRB approved the protocol from 5/6/2019 to 5/5/2024 inclusive. Three weeks before 5/5/2024 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 5/5/2024 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

cc: Stephanie Hoeckley
Joshua Gardner
Stephanie Hoeckley
Elizabeth Buck

BIOGRAPHICAL SKETCH

Stephanie Renee Hoeckley, a Florida native, received her Master of Music degree from Arizona State University in 2015 and her Bachelor of Music degree from the University of Central Florida in 2012. During her time at Arizona State University, she was a Graduate Teaching Assistant in Flute, received Special Talent Awards, and was a recipient of the Jennifer Lowy Dock Fellowship in Music in 2016. In her semester at the University of Arizona in 2015, she was 1 of 20 students to receive the prestigious University Fellowship, an interdisciplinary and professional development fellowship. She has been teaching as Adjunct Flute Instructor at Phoenix College since 2019 and has been an active Board Member of the Arizona Flute Society since 2014. She is a regular teacher and performer at music clinics and conferences throughout North America.