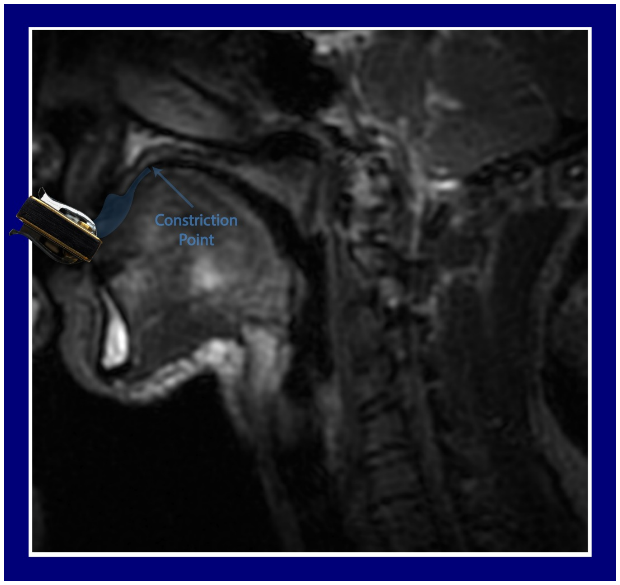


Bending Process on the 10-Hole Diatonic Harmonica with the Visual Aid of Magnetic Resonance Imaging (MRI)

By David Barrett

Introduction

For most instruments, we use sight (visual input) to guide us as to where and how to operate an instrument. We then use touch (tactile input) to produce sound. We finally judge the sound (auditory input) to confirm that a desired pitch was produced and to judge the tonal quality of our actions, allowing us to adjust our touch and/or embouchure to achieve a more desired result. Referencing the piano we can *see* the C Key… *touch* the C Key… resulting in the C Note *sounding*.

The harmonica, in contrast, has no visual reference—the hole numbers inhaled and exhaled upon are inside the mouth during play. The harmonica provides the player with very little tactile feedback—the reed and reed slot of the reed plate used to produce sound are not touched by the player. The harmonica has a smooth face and holes evenly spaced across the range of the instrument, giving no indication of where a player is at in a given point during play. For these reasons, the harmonica player's feedback system is almost entirely auditory, for both learning and performing.

One of the most exciting sounds produced on the harmonica, but most challenging of techniques to perform, is that of *bending* notes. Players bending notes change the pitch of a vibrating reed by precisely locating their tongue in their mouth, tuning their mouth to the desired pitch—each reed and bend requiring a different tuning position. As a harmonica instructor and author of harmonica instruction material for over twenty years, I've refined my description of what's happening on the instrument and what players must do to create this change in pitch (mostly with phonetic reference). However, the lack of a visual reference of what the tongue is doing hampers the learning process.

In early 2012, I asked fellow harmonica enthusiast, Dr. Peter Egbert (Ophthalmology, Stanford University), if we could create high-resolution still and video images of the tongue in the bending process. Peter promptly assembled a team of experts from multiple disciplines: Thomas Rossing (Center for Computer Research in Music and Acoustics, Stanford University), Lewis K. Shin (Radiology, Stanford University, Specialist in Advanced Imaging), Andrew B. Holbrook (Radiology, Stanford University, Expert in MRI Software), Kinya Pollard (Harmonica Customizer, BluesHarmonica.com) and myself (Harmonica Educator, BluesHarmonica.com).

The scientific observations were presented by Thomas Rossing at the Montreal Acoustical Society of America Meeting in June of 2013. The abstract was published in the J. Acoust. Soc. Am. 133, 3590 (2013) and full paper in POMA (Proceedings of Meetings in Acoustics) under the title *Real-time Magnetic Resonance Imaging of the Upper Airways During Harmonica Pitch Bends*. Peter R. Egbert, Lewis K. Shin, David Barrett, Thomas D. Rossing, and Andrew Holbrook and can be viewed and downloaded at http://asadl.org/poma/resource/1/pmarcw/v19/i1/p035075_s1?bypassSSO=1 (found at top "Full Text: Download PDF").

Focus

In this paper the images of our study are presented to provide harmonica instructors and students of the harmonica with a visual reference of the mechanics of the mouth in the bending process. First, the very basics of how the harmonica works.

How the Harmonica Produces Sound

There are 20 reeds on the harmonica—10 on the blow (exhale) reed plate and 10 on the draw (inhale) reed plate. Both reed plates are attached (commonly via screws) to a comb (commonly made of wood) where air is channeled to one pair of reeds at a time. Blowing through Hole 1 vibrates and sounds the 1 blow reed (C on a C Harmonica) and drawing through the same hole vibrates and sounds the 1 draw reed (D on the C Harmonica). Cover plates give the harmonica player a surface to hold the instrument without disturbing the vibration of the reeds.

Figure 1 – Harmonica Reed Plates

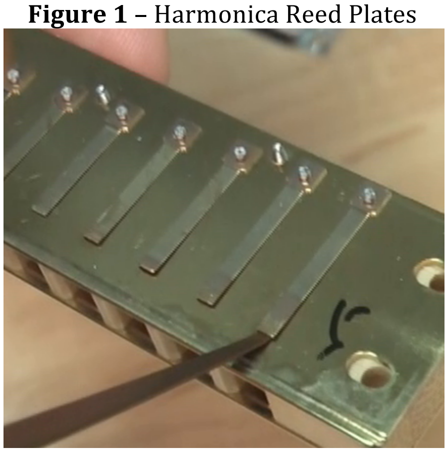


Figure 2 – Harmonica Comb

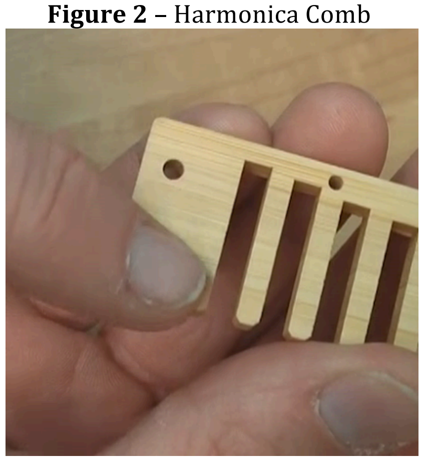
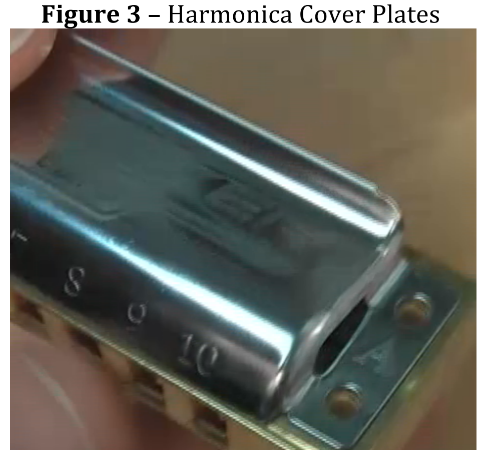


Figure 3 – Harmonica Cover Plates



The "pad" side of the reed, or secure end of the reed, is attached to the reed plate (commonly with a rivet). When activated, the "tip," or free-end of the reed, exits the reed slot (upward swing) and releases a "puff" of air. The reed then re-enters the slot (downward swing) and then starts the upward swing again to release another puff of air. Each puff creates a pressure wave, of which there are approximately 262 per second for the 1 blow reed on the C Harmonica to produce the pitch C4.

To understand how bending works, the pitches of all blow and draw reeds need to be mapped because a pair of blow and draw reeds are involved in the bending process. Detailed in Figure 4 are the notes of the C Major Diatonic Harmonica.

Figure 4 – C Major Diatonic Harmonica

Blow ⟶	C	E	G	C	E	G	C	E	G	C
C	1	2	3	4	5	6	7	8	9	10
Draw ⟶	D	G	B	D	F	A	B	D	F	A

Which Pitches Can Be Produced in the Bending Process

Not every hole (note) on the harmonica can be bent, and not every hole that you can bend allows the same range of bending. The amount of bend you can achieve is dictated by the distance (interval) between the draw and blow reeds in the same hole. In holes 1 through 6 the draw reeds are higher in pitch than the blow reeds, allowing for draw bending. In holes 7 through 10 the blow reeds are higher in pitch than the draw reeds, allowing for blow bending.

Figure 5 shows the chromatic scale, with every note available in our western European diatonic music system. The separation (interval) between each of these notes is a half step.

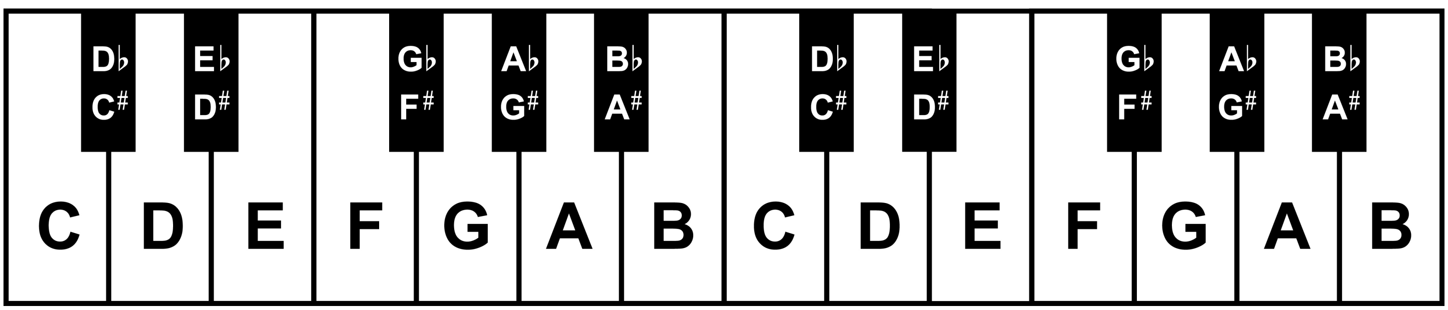
Figure 5 – Chromatic Scale

C C# D D# E F F# G G# A A# B C

D♭ E♭ G♭ A♭ B♭

Musicians commonly use the visual reference of the piano keyboard to convey this same information.

Figure 6 – Piano Keyboard

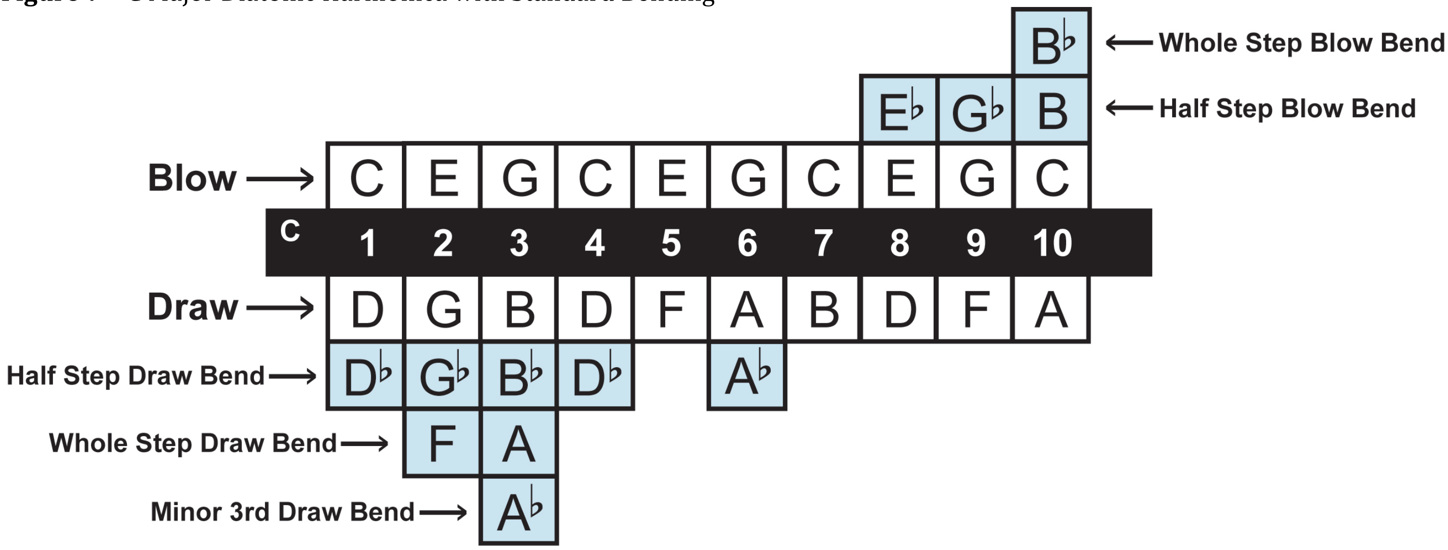


1 draw (noted as "1" in harmonica tablature) is the note D and the 1 blow ("1+" in harmonica tablature) is the note C (a whole step lower in pitch). When performing a 1 draw bend, the player can lower the pitch of the draw reed (D) very close to, but not equal to, the blow reed's natural vibrating pitch (about an eighth of a tone away from C). Players learn to control their embouchure to "stop" at notes within our chromatic system. Referencing the chromatic scale above, this gives us the note D♭ as our target for this 1 draw bend.

Continuing this process with the 2 draw, the player can bend downward to whatever is between the G of the 2 draw and lower pitch of E on the 2 blow. This produces the notes G♭ and F. This process is repeated through the 6 draw. At the seventh hole of the harmonica, the blow reeds are higher in pitch than the draw reeds. The same rule applies here—whatever pitches are between the higher pitched reed (blow in this case) and lower pitched reed (draw reed in this case) are the ones that can be produced by bending.

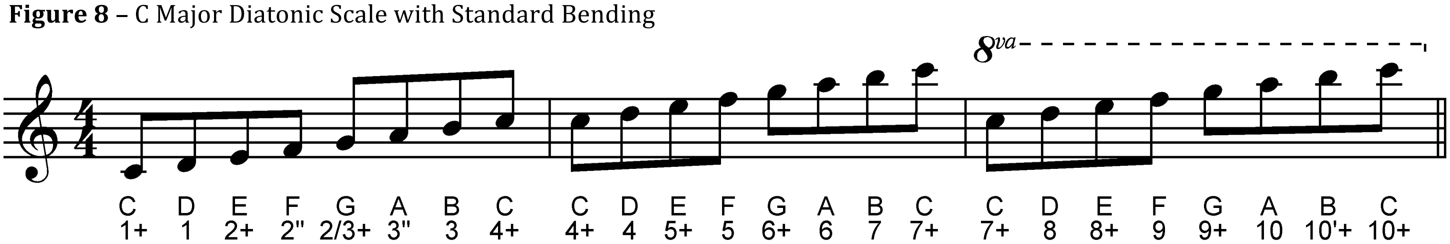
Figure 7 shows all the bends available on the C Major Diatonic Harmonica with the bending process stated. Each slash (') represents a half step bend: 3 = 3 draw (B), 3' = 3 draw half step bend (B♭), 3" = 3 draw whole step bend (A) and 3''' = 3 draw minor third bend (A♭).

Figure 7 – C Major Diatonic Harmonica with Standard Bending



Detailed in Figure 8 are the notes of the C Major Diatonic Harmonica shown on the music staff using standard bending to produce three octaves of the C Major Scale. Below the notes on the staff are the corresponding pitch names and associated harmonica tablature.

Figure 8 – C Major Diatonic Scale with Standard Bending



The Bending Process and What Happens Inside the Harmonica

The best tone on the harmonica is achieved using a large embouchure (think slight yawn), with the jaw slightly dropped, throat open, soft palate raised (closing off the nasal cavity) and tongue lowered. This embouchure produces a large, resonant cavity/chamber for tone production (think of the body of an acoustic guitar—a small body is thin in tone and a large body is full in tone and very resonant).

The reed of a harmonica is analogous to your vocal folds—each vibrating medium needs a large oral cavity to modulate or "shape" the tones. This large embouchure also ensures in harmonica playing that the resonant pitch of the mouth (dictated by the volume of the oral cavity) is lower than the pitch of any reed we may play on the harmonica and their corresponding bends.

The most common issue with new players of the harmonica is their tendency to restrict the size of their oral cavity, mostly due to having a tongue position that is too high in the mouth. Unfortunately for the beginner, it is very difficult to consciously adjust the position of the tongue on demand—or for that matter, even perceive its position (this is known as proprioception—our awareness of the positioning of parts of our body with our eyes closed). A small oral cavity tunes the mouth to a pitch close to a reed being played, which can cause it to be adversely affected—poor tone, reed stalling, squeals and/or unwanted change in pitch (bending). Therefore, a large oral cavity tuned to a pitch lower than any reed on the harmonica causes no unwanted effects and equals good tone.

What starts as a nuisance for players (unwanted pitch change), becomes a desirable affect, if controlled.

To bend a note, the player raises an area of the tongue to the roof of the mouth to effectively create two chambers. The anterior (front) chamber, between the hump of the tongue and the harmonica, has the greatest effect on modulating/tuning the reeds in the bending process.

The player starts the bending process by tuning this anterior chamber to the pitch of the reed they wish to play (this ability comes with experimenting and practice over time). As the constriction point moves back—either by moving the entire tongue back, like a slide whistle, or by gradually rolling the constriction point back in the mouth in a wave-like motion—the size of the anterior chamber enlarges, causing the vibrating reed to produce a lower pitch.

Referencing hole 4 on a C Harmonica, the draw note sounds at the pitch D. As the constriction point moves back in the mouth, the pitch of the anterior chamber is lowered and the D note lowers in pitch. The blow reed is tuned to C, which is a whole step lower than the draw reed. As the bending process lowers the D note of the draw reed, the C reed starts to get excited and vibrates. As the pitch-lowering process continues, pitch production transfers almost entirely to the blow reed, to the point that if you were to take the cover plate off the draw reed side of your harmonica, you could place your finger on the D draw reed when in the full bend and the bent note will continue to sound.

To see a visual representation of this transfer of vibration, reference Figure 7 in *Acoustical and Physical Dynamics of the Diatonic Harmonica* Bahnson H.T., Antaki, J.F., Beery, Q. C. (1998). J. Acoust. Soc. Am 103(4), 2134-2144) http://www.andrew.cmu.edu/user/antaki/articles/Bahnson%20JASA%201998.pdf

Let's now take a look at the tongue and mouth in the actual bending process with the help of our MRI study.

Creating Non-Ferrous Harmonicas to Be Used in the MRI

Though I felt I could produce the same tongue and mouth positions used in the bending process without a harmonica, the team thought the best results would be produced if I played a non-ferrous harmonica in the MRI. We contacted harmonica customizer Kinya Pollard (known in the harmonica world as the "HarpSmith") and he created a harmonica that used a plastic comb and cover plates with aluminum plates and reeds. He also cut the reed plates down to be as small as possible to minimize metal in the harmonica.

Pollard produced two harmonicas for us to test, one for a 3 draw bend (C Major Diatonic Harmonica tuning in red, 3 draw B and 3 blow G) and the other for an 8 blow bend (C Major Diatonic Harmonica tuning in green, 8 blow E and 8 draw D). Though we imaged both harmonicas, the red harmonica built to demonstrate hole 3 draw bend serves our purpose well for this paper.

Figure 9 – Non-Ferrous Harmonicas built for this MRI Study by Kinya Pollard (The HarpSmith)

Figure 10A – 3 Blow Reed (G)

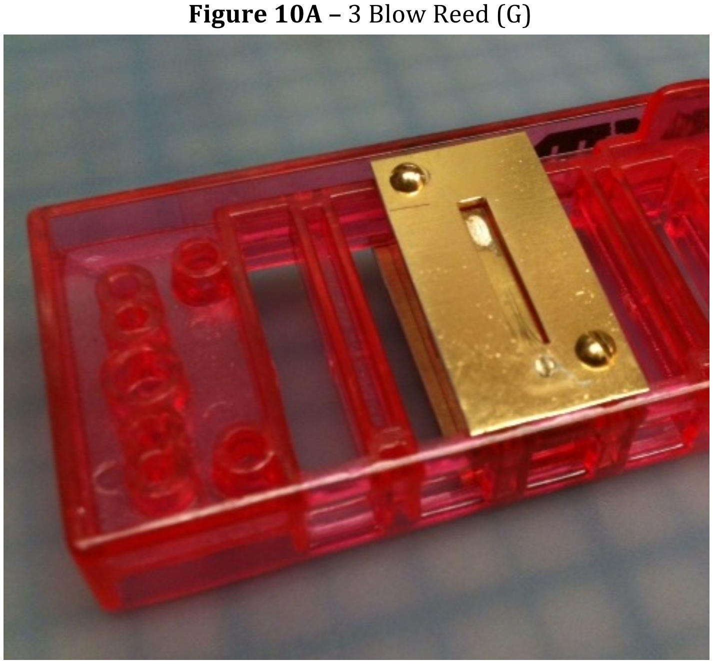
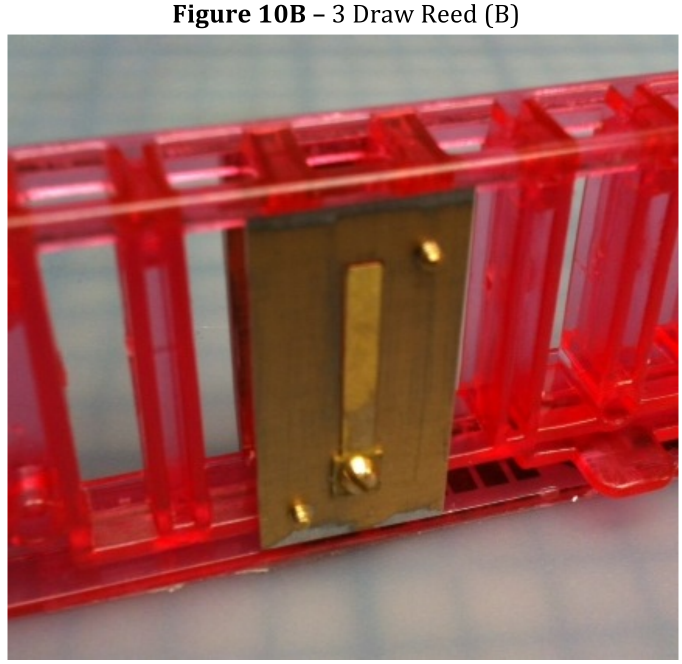


Figure 10B – 3 Draw Reed (B)

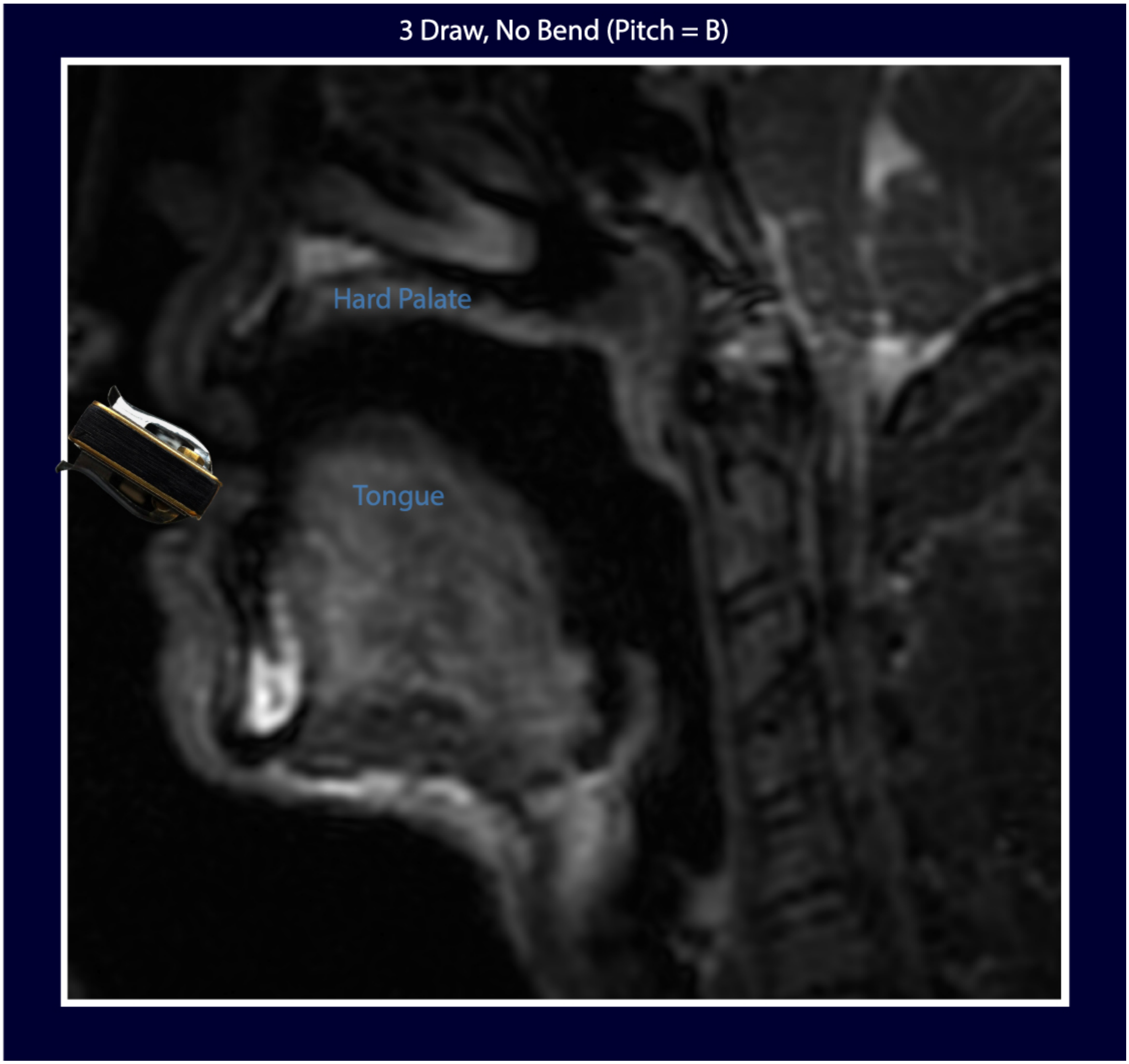


Results: Images of the Bending Process using MRI

All the images shown here are adapted from the paper published in POMA (Proceedings of Meetings in Acoustics) under the title *Real-time Magnetic Resonance Imaging of the Upper Airways During Harmonica Pitch Bends* Peter R. Egbert, Lewis K. Shin, David Barrett, Thomas D. Rossing, and Andrew Holbrook and used with permission from the Journal of the Acoustic Society of America.

Figure 11 shows the harmonica in the mouth, with a normal tongue block embouchure used for the production of good tone. The harmonica pictured in Figure 11 is simulated to give you a better representation of its relative position in the mouth since it can't be seen in the MRI image. Though the MRI machine was loud, I did not have a problem hearing the notes I was playing on the harmonica.

Figure 11 - Lateral view of me while maintaining a normal embouchure for playing an unbent note



In Figure 11, the hump of the tongue is clearly visible, although it is far below the roof of the mouth (hard palette). Hence, the oral cavity is comprised of one large chamber. This contrasts with the tongue position used for a draw bend—as seen in Figure 12. This is an antero-posterior (front to back) view of me with the most elevated part of the tongue almost touching the roof of the mouth. Accordingly, only a narrow channel (black area within the circle) remains open.

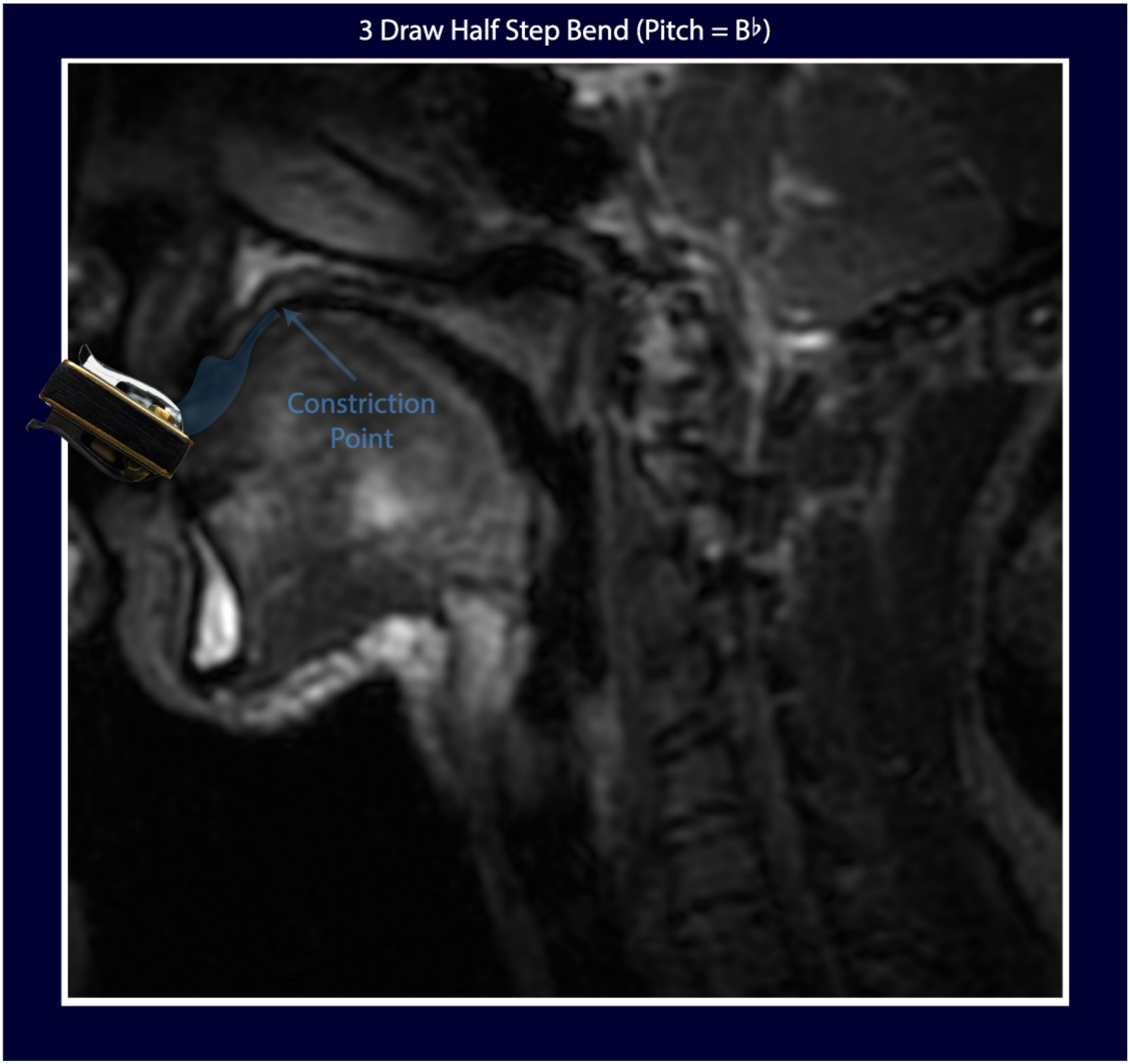
Figure 12

The placement of the tongue in bending is very similar to the spoken E, as demonstrated in Figure 13.

Figure 13

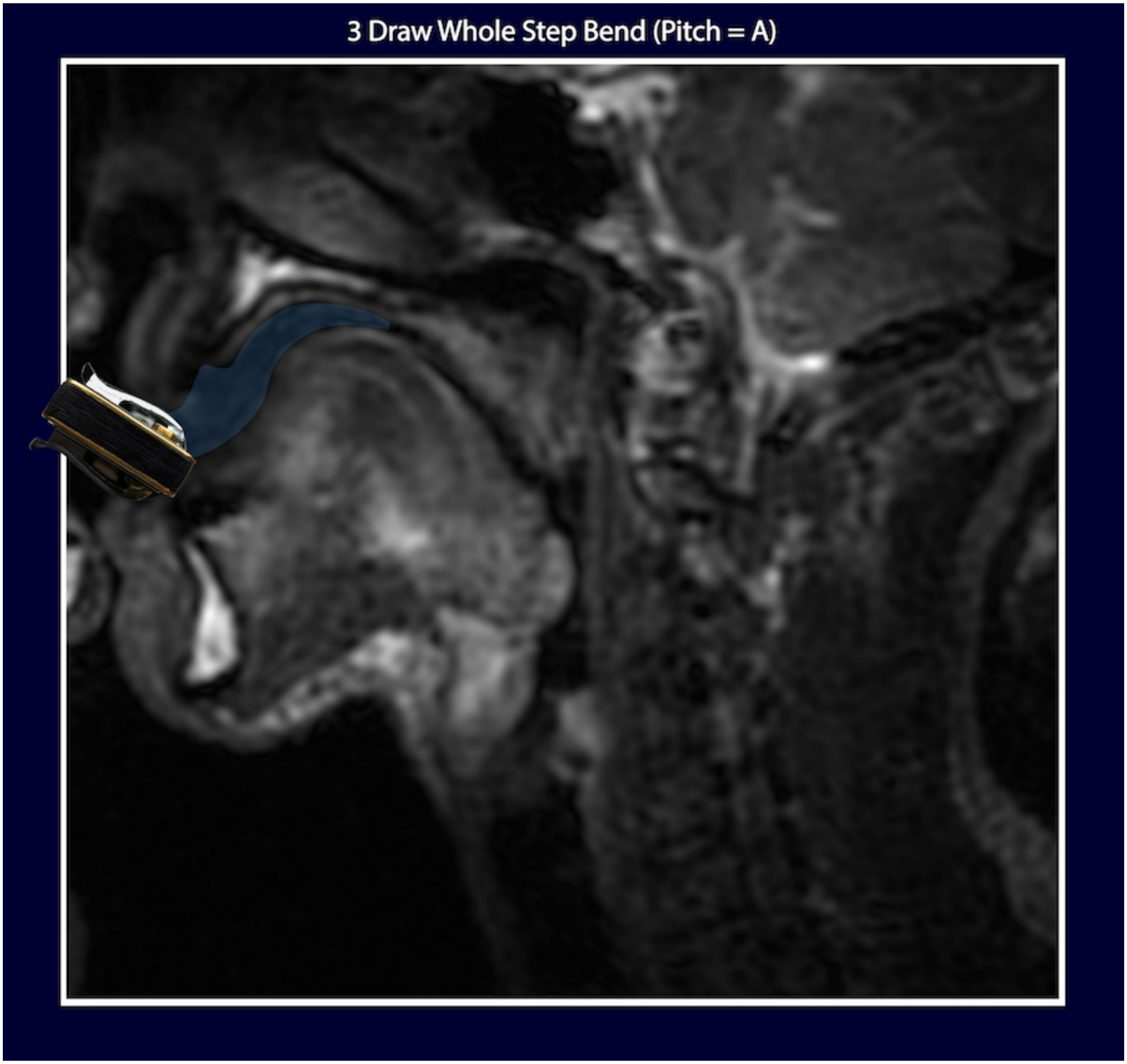
Just humping the tongue is not enough for the bend to occur, the tongue must be humped in a place where the volume in front of the hump of the tongue to the face of the harmonica (anterior chamber) is tuned to the pitch of the draw reed (in our case, the note B on the C Harmonica). The player then moves the constriction point further back in the mouth to enlarge the chamber (by gradually rolling the constriction point back in the mouth, in a wave-like motion) and sound the lower pitch. Figure 14 demonstrates in light blue this volume. When helping students to perform this bend, I commonly use "Sh" as an approximation of the location for this slight bend.

Figure 14



To deepen the bend, the player again moves the constriction point further back in the mouth, enlarging the anterior chamber and thus lowering its pitch. Figures 15 demonstrates this lowered pitch—note the larger chamber in light blue. I commonly use “Kee” as an approximation of this bend location for students.

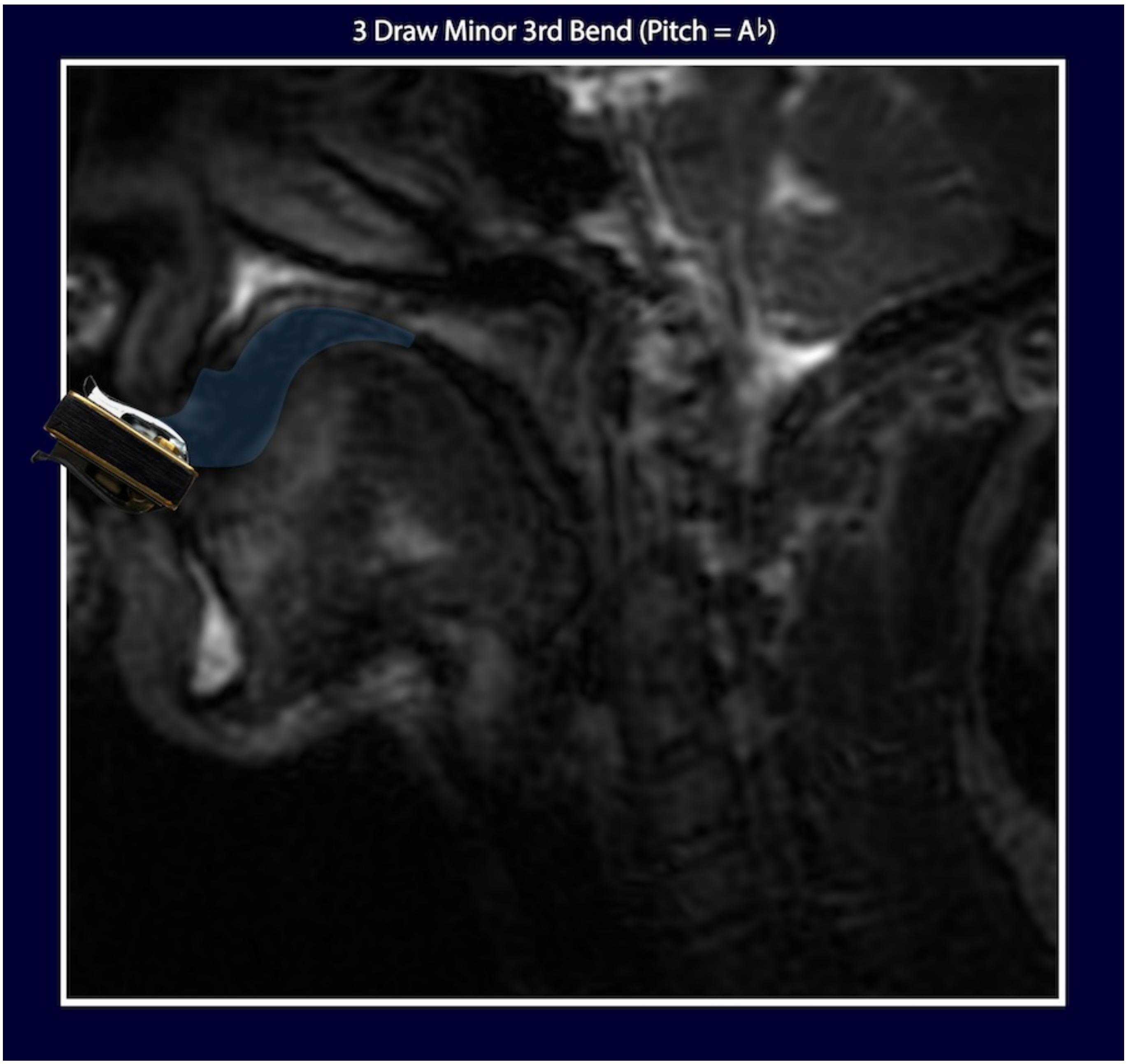
Figure 15



Hole 3 draw on the harmonica can bend even further. Figure 16 demonstrates this. I commonly use "Koo" as an approximation of this bend location for students. Note that the hump of the tongue, where the constriction point is found, has not moved much further back than that of the 3 Draw Whole Step Bend in Figure 15, but the tongue in the anterior chamber has lowered to create a more concave, or "scooped" shape, and thus the larger chamber needed for this lower-pitched bend is created. Creating this "scooped" shape can be a key element in bending low notes/reeds. I recommend students looking to deepen their bends (commonly on holes 3, 2 and 1 on the A Harmonica and below) experiment with this scooped shape.

It can be helpful for students to observe what their tongue is doing during the bending process. I suggest they take the harmonica out of their mouth, place the tip of their tongue behind their lower set of teeth to simulate the tongue being placed on the harmonica in the tongue block embouchure, and open their mouth large enough in front of a mirror to visually observe their tongue shape in the bending process.

Figure 16



Players can bend in any of the common embouchures. The process is the same—hump a portion of the tongue to the roof of the mouth to tune an anterior chamber to the pitch that you desire to produce in the bend. Figure 17 shows the 3 draw whole step bend using the pucker embouchure.

Figure 17

Size of the Anterior Chamber Relative to Pitch

If we were to show the bending process for every hole on the harmonica, you would observe that the higher-pitched reeds require the use of more of the front of the tongue, more forward in the mouth, to create the small anterior chamber needed to produce the high-pitched bend. The lower-pitched reeds require the use of more of the back of the tongue, in the rear of the mouth, to create the larger anterior chamber needed to produce the low-pitched bend. Think of the size of the anterior chamber as being analogous to that of a pea for a 10 blow bend, a grape for a 6 draw bend and a plum for a 1 draw bend.

Closing Words

I hope you've found these images helpful in your understanding of the bending process and helpful in creating a mental picture of what you're trying to reproduce in your mouth. Your focus is to now experiment—mastering the art of bending is a process that takes time, experimentation, perseverance and patience. If you would like to learn how to implement the different levels of bending proficiency into your playing, join me for lessons at BluesHarmonica.com—it will be my pleasure to work with you.

Video Footage of the Bending Process from our Study

MRI Video Footage (YouTube)
1) http://youtu.be/I5kogDrivvQ

MRI Video Interview of Study (YouTube)
1) http://youtu.be/I5ZjNUWnhgk
2) http://youtu.be/ngDmx340aKk
3) http://youtu.be/0nmWRcb4oP8
4) http://youtu.be/XojA6RZ0Om8

To see the video footage that preceded this study visit:

Physiology of Playing the Harmonica
By Henry T. Bahnson, MD http://www.youtube.com/watch?v=gTEXSb6duVs

Fluoroscopic (X-Ray) Video of Harmonica Playing
By Jim "Turbodog" Antaki (U Pittsburgh Medical Center)
http://www.youtube.com/watch?v=7bcVYWyTt0g&list=TLFSbMHZe4740

Unseen X-Ray Harmonica
By Drs. Henry T. Bahnson and James F. Antaki (University of Pittsburgh, Department of Surgery)
http://www.youtube.com/watch?v=yeTTs5bc_P4&list=TL-iTXrO9L76A

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  - Pat Missin (patmissin.com)
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  - Winslow Yerxa (bluesharmonica.com)
  - Rick McCombs
  - Dennis Carelli