Article

Movements of the Tongue during Lip Trills in Horn Players

Real-Time MRI Insights

Peter W. Iltis, PhD,[1,3] Jens Frahm, PhD,[2] Dirk Voit, PhD,[2] Arun Joseph, PhD,[2] Eckart Altenmüller, MD,[3] and Aaron Miller[1]

OBJECTIVE: Movements inside the oral cavity during lip trilling in horn-playing are poorly understood and controversial, particularly with respect to pedagogy. Developments in real-time magnetic resonance imaging (RT-MRI) allow representations of oral cavity movement during lip trill performance on a MRI-compatible horn to be recorded and quantified. **METHODS**: We present RT-MRI data on 11 highly skilled horn players obtained from serial images acquired at acquisition times of 33.3, 18.2, and 10.0 ms (i.e., at 30, 55 and 100 frames/sec) as they performed sixteenth note, whole-step trills between E♭4 and F4 (concert pitch) at two tempos, ~60 bpm and as fast as possible. **RESULTS**: For fast trilling (mean speed 178.3± 24.7 bpm), 7 of 11 subjects exclusively utilized a tongue movement strategy, 3 used both a tongue and jaw strategy, and 1 exclusively used a jaw strategy. For trilling at ~60 bpm, all 11 subjects used a tongue movement strategy. **CONCLUSIONS**: We suggest using these movement strategies in teaching whole-step trills. *Med Probl Perform Art* 2017; 32(4):209–214.

In the music literature, there are occasions when a musician is required to slur very rapidly and repeatedly between two notes separated by a whole step, a technique known as a trill. For many instruments, this simply requires alternating fingers between notes (e.g., keys on a piano) or rapidly pressing and releasing a key or valve (e.g., flute or trumpet). For French horn players, this is possible for half-step trills, but not so for whole-step trills. Commonly referred to as a lip trill, these whole-step trills can be difficult to master. Indeed, the ability to trill at varying dynamics and with fluency is one of the critical performance traits distinguishing highly advanced hornists from aspiring hornists of lesser ability. There is considerable variability in opinions among players and teachers regarding desirable lip trill mechanics. Ideas for producing successful trills include creating subtle movements of the lips within the mouthpiece,[1,2] alternating vertical movements of the jaw,[3] moving the tongue within the oral cavity,[2,4–6] and even shaking the instrument, though the effect produced by this is more commonly used in jazz trumpet playing and is quite undesirable for horn players.[7]

Discerning the movements that occur during successful trill production is difficult unless the performer employs obvious jaw movements or pronounced lip movements. However, some teachers insist that no visible movements of either the lip or jaw occur if lip trills are done properly, though this is controversial.[2] Advocates for tongue movements inside the oral cavity often refer to rapidly alternating between an "*aw-ee*" or "*oo-ee*" vowel position of the tongue as cues for teaching proper trill technique.[1,2,4–8] However, this latter method relies purely upon the subjective kinesthetic perceptions of its advocates, as visualizing such subtle tongue movements has been impractical in the past.

With the recent developments applying real-time magnetic resonance imaging (RT-MRI) technology to the study of brass playing,[9–12] it is now possible to study lip trills much more closely with respect to activity within the oral cavity. Lip trills occur at very high speeds, and we have shown that any image acquisition rate below 100 frames/sec (fps) cannot accurately measure very fast movements like double tonguing.[13] There is no published work to date attempting to use high-speed RT-MRI to study lips trills, and these films should have adequate, temporal resolution to capture rapid movements inside the mouth during lip trills.

The purpose of this study was to utilize high-speed RT-MRI techniques in descriptively examining oral cavity movements that occur during lip trilling at a slow tempo

From the [1]Department of Kinesiology, Gordon College, Wenham, MA, USA; [2]Biomedizinische NMR Forschungs GmbH am Max-Planck-Institut für biophysikalische Chemie, Göttingen, Germany; and [3]Hochschule für Musik, Theater und Medien, Hannover, Germany.

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Address correspondence to: Dr. Peter W. Iltis, Dep. of Kinesiology, 255 Grapevine Rd., Gordon College, Wenham, MA 01984, USA. Tel: 978-867-4088. peter.iltis@gordon.edu.

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FIGURE 1. Photo of subject inside the MRI scanner, shown from the subject's feet, with the instrument outside the scanner.

(sixteenth notes at 60 bpm filmed at either 30 or 55 fps) and at the fastest possible tempos (filmed at 100 fps) in elite horn players.

METHODS

Participants

Eleven healthy, elite horn players (mean age 54 yrs, range 27–66) volunteered for this study. Five of the performers were recruited from major European orchestras, two were internationally active touring soloists, and the remaining four were university or conservatory faculty with varied "by-appointment" ensemble and solo commitments. The published guidelines established by the local ethics committee at the Max Planck Institute in Göttingen, Germany, were strictly followed, and all subjects submitted written informed consent in compliance with the regulations established by this committee.

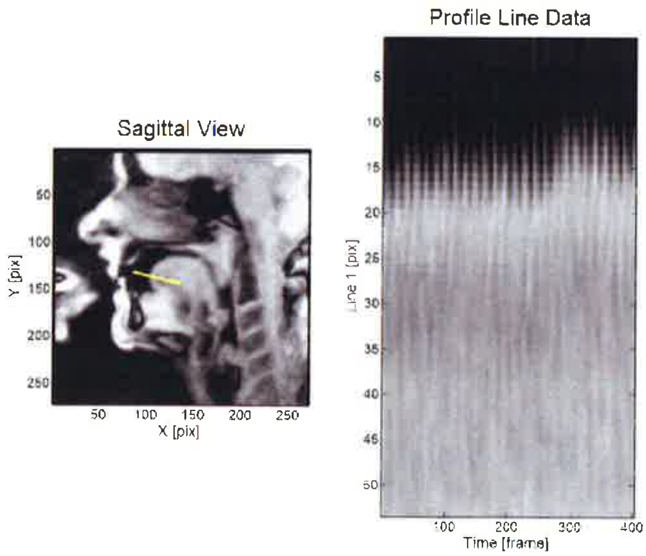

FIGURE 2. *Left*, Sagittal view of a typical subject (mid-trill) showing position of the profile line in determining tongue movement. *Right*, Resulting profile line graph of temporal luminescence changes. Vertical striping (pixels ~10–20) represents rapid movements of the tongue edge.

Procedures

Performance Tasks and Equipment

Prior to testing, all subjects were given a warm-up period outside the scanner during which they could practice playing on a valve-less horn, pitched in the key of Eb concert (Richard Seraphinoff, Bloomington, IN, USA, builder). The bell of the horn is non-ferromagnetic and, during MRI, sits at the feet of the supine subjects on the scanner table. A length of graduated plastic tubing connecting the bell to the mouthpiece runs at the subject's side, extending up into the scanner itself (Fig. 1).

The horn players grasped the mouthpiece and brought it into playing position for each experimental trial. An assortment of plastic mouthpieces of varying sizes was available (Harrison Mouthpieces, Inc., Vancouver, BC, Canada), and the performers chose the one that most closely resembled their own. After warming up, each subject assumed a supine position on the MRI scanner table, with the horn secured in position.

An intercom system allowed communication between the subjects and experimenters, as well as a means to play audio examples of the exercises. Once inside the scanner, all subjects listened to an audio example and subsequently performed a lip trill between E♭4 and F4 (concert pitch, mid-range of the instrument) under two conditions. The first involved playing a sixteenth note trill for at least two full measures (4/4 time signature) at approximately the same tempo as the audio example, 60 bpm. Actual performance tempos varied slightly, as can be seen in Table 1. The second comprised the same exercise, but performed as fast as possible.

Real-Time MRI and Audio Data Acquisition

As in previous studies,[9,11,13,14] a 3T MRI system (Magnetom Prisma, Siemens Healthcare, Erlangen, Germany) equipped with a 64-channel head coil was used to obtain the images. RT-MRI was based on previously established techniques.[15] Radially encoded gradient-echo images (1.96 ms repetition time, 1.28 ms echo time, 5° flip angle) were obtained at rates of 30 or 55 fps (33.32 and 18.18 ms resolution, 60-bpm trials) and 100 fps (10.00 ms resolution, fast trill trials) with 1.4 mm in-plane resolution, 8-mm slice thickness, and 192 × 192 mm^2 field-of-view. The different acquisition rates for the 60-bpm trials simply reflected different testing dates. In sessions conducted prior to August 2015, all except high-speed movements involved filming at 30 fps. After that date, technological advances allowed the same image quality at the faster 55-fps rate, and this became the default filming speed for the slower speed trill. All movies and images had a sagittal orientation cutting the oral cavity exactly in the midline.

A MR-compatible optical microphone (Dual Channel-FOMRI, Optoacoustics, Or Yehuda, Israel) was attached to the bell of the horn, and sound recordings were later synchronized to the films using the procedure described by Niebergall et al.[16,17] When subjected to standard audio processing software (Audacity: http://audacity.sourceforge.net), the audio tracks provided information pertaining to the frame range and time duration corresponding to the trills. For all trills, a 4-second segment was selected during which trilling was audibly consistent. For the ~60-bpm trials, the number of frames analyzed were thus 120 and 220 for the 30- and 55-fps trials, respectively, and for the trial performed "as fast as possible" (100 fps), 400 frames were studied.

RT-MRI Film Analysis

As in previous studies,[9–13] a customized RT-MRI toolbox was employed (MATLAB R2014a, Natick, MA, USA, including the Image Processing and Signal Processing Toolboxes) to extract quantitative information from the films. By examining each film to detect where movements occurred, the tongue and jaw became the main regions of interest for study. Edges of both structures were seen in each frame, identified as distinct luminescence contrasts (bright = tissue, dark = space) between adjacent pixels. (Videos showing the slow and fast trilling exercises in one typical subject are available in the online version of this paper.)*

Using MATLAB, a reference (profile) line was positioned perpendicular to the direction of movement of these edges, and changes in pixel luminescence along this line were plotted as a function of time. Figure 2 shows typical tongue surface movements during a top speed trill filmed at 100 fps. In the left panel (sagittal view), the position of the profile line is depicted, and in the right panel, the profile line graph generated by MATLAB shows movements along this line occurring quite rapidly and at regular intervals (Fig. 2, right panel, with vertical striations between pixels 10 and 20). When these data were subjected to further image processing analysis involving the calculation of temporal gradients,[12] frequency data were obtained from which the movement tempo (bpm) was calculated.

Figure 3 illustrates the temporal gradient plot (differentiation of pixel luminescence across time) for the trial depicted in Figure 2. In Figure 3, dark (colored) areas appear in regular intervals across time, emphasizing temporal changes in luminescence due to the fast movements of the tongue edge. Further analysis in MATLAB yields a time series plot of the change rate of luminescence (Fig. 4).

A Fourier transform and plot of these time series data produced a frequency spectrum as illustrated in Figure 5. The dominant frequency in this figure occurs at 6.348 Hz, representing the onset of the first note in each trill pair (E♭4 à B♭4). Since each trill pair represents the first 2 of 4 sixteenth notes, this dominant frequency is doubled to calculate the number of individual notes per second (~12.7). Multiplying this by 60 calculates the number of notes per minute (762), and since there are 4 sixteenth notes per beat, this product, divided by 4, yields the tempo of the movement in bpm (~191).

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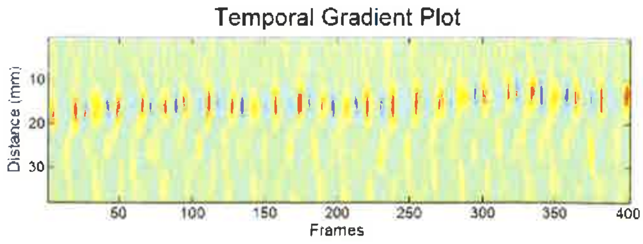

FIGURE 3. Temporal gradient plot of the subject shown in Fig. 2, trilling as fast as possible for 4 sec, acquired at 100 fps.

Comparison of these movement tempos to the audio tracks of each film established whether they were in synchrony with note changes. This was done using the aforementioned Audacity software by importing the .wav sound file for each trial, selecting the same time period that was analyzed in MATLAB, determining the duration of that period, and counting the number of note changes during playback. Playback was at one-quarter speed to make the counting easier. The calculated note frequency allowed determination of the tempo, as described above.

Jaw movement was determined using the same techniques, with the only difference being the placement of the profile line. Figure 6 provides an example that is analogous to Figure 2.

RESULTS

Table 1 presents findings for all 11 subjects for tongue and jaw movement when trilling as fast as possible and at the suggested slower speed of 60 bpm. For fast trilling, 7 of 11 subjects exclusively utilized a tongue strategy, 3 used both a tongue and jaw strategy, and 1 exclusively used a jaw strategy. Trill speeds (sixteenth notes) ranged from 146 to 211 bpm, with an average of 178.3±24.7 bpm. These trill speeds, derived from RT-MRI analyses, were in very close agreement with speeds determined from analysis of the audio tracks (174.4±21.3 bpm). For the slower trill, all 11 subjects moved the tongue, with 2 subjects using the jaw as well. Ostensibly, because of the lack of a metronome, there was some variability in speed from the suggested 60 bpm.

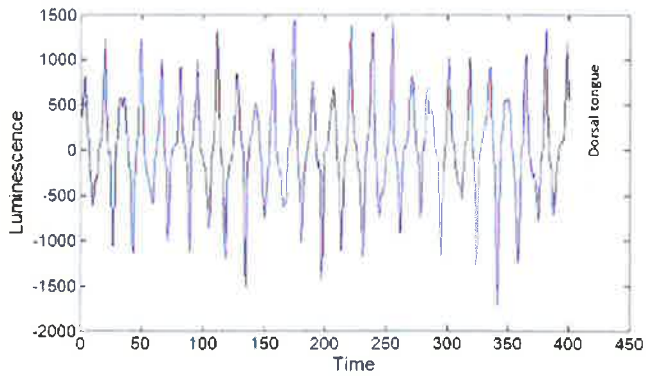

FIGURE 4. Time series plot derived from Fig. 3 data, showing rate of change in luminescence.

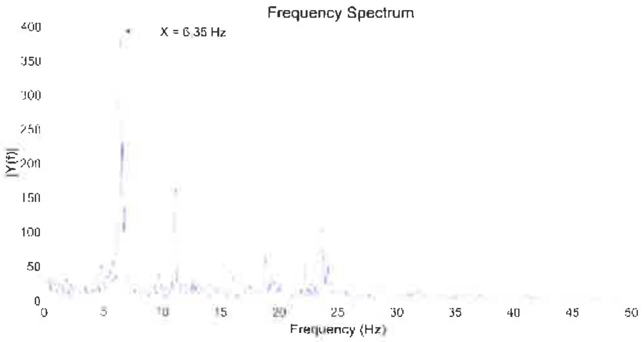

FIGURE 5. Fourier transform of data from Fig. 4. The dominant frequency is ~6.35 Hz.

DISCUSSION

Our data clearly demonstrate that whole-step trilling, commonly referred to as lip trilling, is an activity that involves movements of the tongue, jaw, and/or both in the majority of our sample of elite horn players. With the exception of one subject who exclusively used a jaw strategy at the fastest tempo, all of our elite players involved the tongue in this skill, whether trilling at a controlled, slow tempo or as fast as possible. Interestingly, the subject using a jaw strategy on the fast trilling trial used a tongue strategy at the slow tempo, just like the others. Hence, it may be pertinent to re-name this skill as "whole-step trills" rather than "lip trills." As a possible limitation of our study, it is fair to mention that we only had a side view of the lips. It is therefore possible that some subtle movements of the lips were undetectable with our technique, but this is only speculation.

It is noteworthy that the movement patterns of the tongue were not all the same for all performers. That is, while most of our players (8 of 11) seemed to move the tongue with the orientation depicted in Figure 7, right panel, the remainder used a strategy more like the left panel.

These findings, for the first time, objectively affirm the assertions of many horn teachers who have attempted to explain how whole-step trills are executed.[1,2,4,5,7,18,19] Though it is possible that there are exceptions to our sample of elite players among horn players worldwide, the clear pattern seen here in players who trill extremely well is compelling. We argue that in teaching whole-step trills,

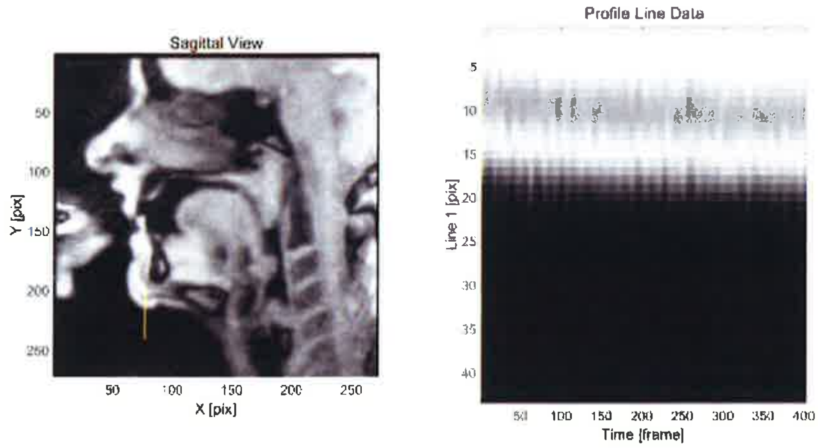

FIGURE 6. *Left*, Sagittal view of a typical subject (mid-trill) showing position of the profile line in determining jaw movement. *Right*, Resulting profile line graph of temporal luminescence changes. Vertical striping (pixels ~16-20) represents rapid movements of the jaw edge.

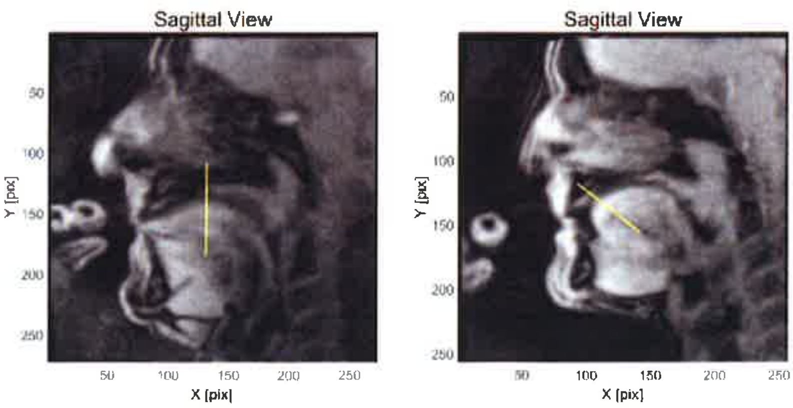

FIGURE 7. Examples showing the two predominant movement orientations of the tongue: forward and upward (*right panel*) and vertically (*left panel*).

TABLE 1. Movement Strategy Employed and Tempo Achieved (as Calculated by MATLAB) When Trilling as Fast as Possible and at ~60 bpm

	As Fast As Possible			At ~60 bpm		
	Movement Strategy		Tempo	Movement Strategy		Tempo
Subject	Tongue	Jaw	bpm	Tongue	Jaw	bpm
1	Yes	No	211	Yes	No	60
2	Yes	No	158	Yes	No	105
3	Yes	Yes	164	Yes	No	60
4	Yes	No	199	Yes	No	81
5	Yes	No	193	Yes	No	67
6	No	Yes	158	Yes	No	ND
7	Yes	No	211	Yes	No	53
8	Yes	No	146	Yes	No	67
9	Yes	Yes	188	Yes	Yes	64
10	Yes	Yes	188	Yes	Yes	71
11	Yes	No	146	Yes	No	74

ND, no data available due to the inability of MATLAB to detect movements clearly.

educators would do well to find ways to convey these findings to students. The suggestion of subtle vowel changes, as mentioned in the introduction to this paper, seems to be one such way, though the choice of vowel sounds appears more nuanced than previously considered. For example, Farkas' suggestion[7] of using the vowel sounds "*oo-ee*" to alternate between notes is probably unwarranted, as the "*oo*" sound is as much a consequence of protruding the lips as it is a result of moving the tongue vertically within the mouth. Such simultaneous movement of the lips and tongue is impractical in horn playing. Here, motor control of the interplay of lips and tongue is much more difficult, since movements are relatively large, resulting in difficulties to obtain precision within the millimeter range, corresponding to Fitt's law.[20] In fact, the extremely small tongue displacements occurring with no lip movement demonstrated in this work of between ~5-8 pixels, or ~3.75 – 6 mm (see Figs. 2 and 6, right panels), suggest that the vowel sound differences are much less obvious, and economy in movement amplitude is usually important. The alternative use of "*eh*" and "*ee*", for example, requires very little tongue movement with no change in lip position. Perhaps coaching the student to form an embouchure position with the lips, and then practice very slight and fast tongue movement similar to those shown here, would be helpful. Experimentation with this as well as perhaps employing subtle and rapid chin movements appears warranted and may help the student to discover what works best.

We made no attempt to examine movements of the tongue and jaw during trills in other parts of the horn's register. Because the distance between adjacent pitches in the natural overtone series become greater as one descends and smaller as one ascends, it is possible that the amount of movement used, whether in the tongue or the jaw, is greater or smaller, respectively. On the other hand, whole-step trills on the horn are rarely done below the chosen trial pitches of E♭4 and F4 (concert pitch), and trills on higher pitches become less troublesome because of the acoustic properties of the instrument.[7]

These observations provide much-needed clarification of the movements involved in whole-step trilling, but the physics that explain efficacy are not obvious and lie beyond the scope of this paper. Probably, individual solutions are found via subconscious auditory-sensorimotor integration depending on the biomechanics, anatomy, and "sound-ideal" of the respective horn player. The interplay between these factors needs to be clarified in a larger sample of subjects, including novices in follow-up studies documenting the process of procedural learning in such a complex task.

Conclusion

Our study strongly indicates that any suggestion of employing minimal or no motion of the tongue and/or jaw to accomplish successful whole-step trilling is incorrect. Our sample of excellent horn players provides data showing that very slight anterior/vertical movement of the tongue is a common and effective movement strategy accompanying extremely fast trilling, as well as vertical movements of the jaw and/or tongue. We therefore recommend that horn teachers develop instructional strategies that allow students to make use of these movements as they empirically discover the keys to performing this technique.

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APPENDIX: Sample Videos of Trilling Exercises

Slow trilling at ~60 bpm

Fast trilling, as fast as possible

VIDEO. Sample videos showing the slow and fast trilling exercises for one typical subject: https://www.sciandmed.com/mppa/video/32.4.209.