Evolving Tooka: from Experiment to Instrument

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ABSTRACT
The Tooka was created as an exploration of two person instruments. We have worked with two Tooka performers to enhance the original experimental device to make a musical instrument played and enjoyed by them. The main additions to the device include: an additional button that behaves as a music capture button, a bend sensor, an additional thumb-actuated pressure sensor for vibrato, additional musical mapping strategies, and new interfacing hardware. These developments arose through experiences and recommendations from the musicians playing it. In addition to the changes to the Tooka, this paper describes the learning process and experiences of the musicians performing with the Tooka.

Keywords
Musician-centred design, two-person musical instrument.

1 INTRODUCTION
The *Tooka* was created as an exploration of two-person musical instruments. The original Tooka [3] was a hollow tube with a pressure sensor and three buttons for each player. Players placed opposite ends in their mouths and modulated the pressure in the tube with their tongues, cheeks and lungs, controlling the sound. Coordinated button presses controlled the pitch selection. The first Tooka was played by amateurs who could play simple music but did not have time or expertise to explore the expressive capabilities of the Tooka. Based on recent experiences of two trained musicians playing with the Tooka, we have evolved the design. This paper describes the experiences these two musicians had with learning to play the Tooka and the expressive capabilities they feel when playing. Figure 1 shows two people playing Tooka and Figure 2 illustrates the new Tooka.

Tooka continues some of the pioneering work in multi-person musical instruments. Some early explorations in this direction are found in works such as *Mikrophonie I and II* [9], *Laboratorium* [4], and groups such as the League of Automatic Music Composers [1] and the Hub, experimental computer network bands [5]. In *Mikrophonie I*, expert percussionists play a collective instrumented Tam-Tam that has controls for augmenting the sound intended for 2 sets of three players. In

Figure1: Two musicians (authors) playing Tooka.

Mikrophonie II, a four-person chorus along with music from an organ is fed through a ring modulator played simultaneously. The League of Automatic Music Composer*s* was the first computer network trio. The Hub connected six electronic musicians in a computer network that made each player's activity accessible to other players thus enabling the group to engage in collective musical improvisation. The tradition of collaborative instruments for expert play and performance where a second player modulates, either mechanically or electronically, the live performance of another expert player continues in works such as *Contacts Turbulants* using the "catch and throw" metaphor [10] and the performance using the Photosonic instrument [2].

Based on an understanding of the relationship between control and musical output, several hypotheses were made about how musicians would respond to the Tooka [3]. The main hypotheses were:

1. intimacy between two people would grow as they learned to use the Tooka and that this intimacy would provide continually increasing levels of expressive capabilities;
2. tongue movements would lead to the most control over

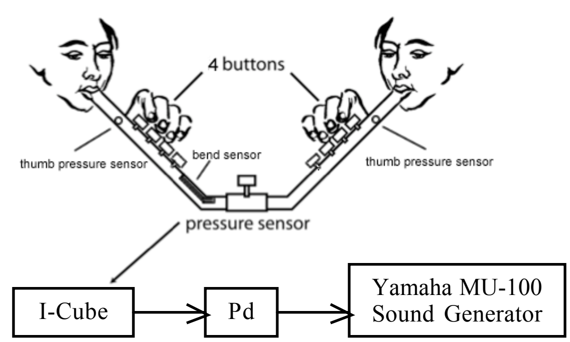

Figure 2: Block diagram of the Tooka.

the pressure sensor

3. a fourth button would be required for a larger control space

In addition, we created the musical mapping with the intent that musicians would have to coordinate their button presses to fully explore the musical range of the instrument

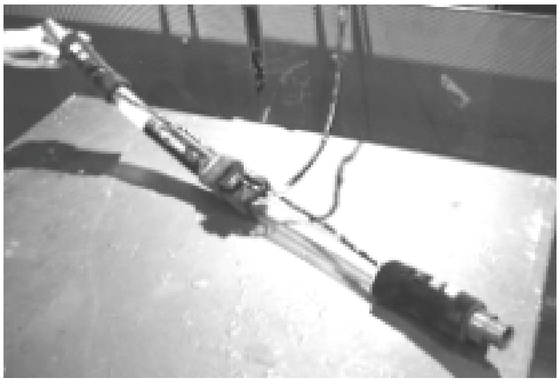

Figure 3: Tooka

Two musicians, Linda Kaastra, a trained bassoon player, and Sachiyo Takahashi, a trained Noh flute and recorder player, practiced for 15 hours with the instrument making recommendations as they progressed. Within this time, they were able to learn the basic techniques of the instrument and develop sufficient skill to perform as well as to be part of an improvisational group using traditional instruments. They have begun to explore many of the expressive capabilities of the instrument. Section 3 describes their experiences with the instrument.

Based on their experiences we validated our first and third hypothesis and invalidated our second one. As a result, we improved the interface. Additionally, the choice of button mapping resulted in some unanticipated and interesting results. Specifically, it was possible for players to coordinate button presses in the creation of a melodic line, but it was also possible to play solo (independent) parts within a limited range. The interplay of the musicians became important in the development of methods for allowing turn-taking and coordinated actions for expressive effect.

This paper first describes the new system including the changes from the original Tooka. The focus shifts then to the experiences of the two musicians. These experiences add to the body of knowledge about how intimacy forms between a player and a new instrument for musical expression. What is particularly interesting when it comes to two-person musical instruments, is how the dynamics of the two people influence the development of intimacy between them as well as with the instruments. Finally, new developments and enhancements of the system will result as musicians continue to practice and refine their abilities. These are discussed as future directions for the Tooka.

2 HOW TOOKA WORKS

The current version of the Tooka uses two identical sections of hollow flexible tube connected together with a plastic connector to form one continuous tube. At each end is a mouth-piece made from a connector, four buttons and a pressure sensor. The tube's outside and inside diameters are 1.25" and 1", respectively, providing a fairly high compliance. When assembled, the Tooka measures 86cm long. Attached to one side is a bend sensor, which responds to flexing of the tube. An air pressure sensor in the center measures the air pressure inside the tube. Blue velvet coverings and black tape on all the wires were added by one of the musicians to improve the visual and tactile aesthetics for the performers. The instrument is shown in Figure 3. Two people demonstrating how to play the Tooka are shown in Figure 1. To play the Tooka, each player puts their mouth over opposite ends forming a sealed tube. The players collectively modulate the tube pressure to control sound. Each player has four buttons that may be used to control mode changes, such as pitch as described in section 2.1. Players can modulate the pressure in the tube using either their tongue, cheeks, pharynx, or diaphragm.

The Tooka's air pressure sensor is a NovaSensor 410-015G3L that detects medium range pressures. The air pressure sensor is connected to an instrumentation amplifier and the signal is passed to an I-Cube from Infusion Systems. Both hardware and software calibration are used for this sensor. The buttons are also connected to the analog inputs of the I-Cube but they are thresholded to behave as digital inputs. The bend sensor and two thumb-pressure sensors feed into the analog inputs of the I-Cube. The I-Cube feeds data from the sensors into a Pd patch [7]. All the music code for mapping sensor data to MIDI control codes is performed within Pd. The Yamaha sound generator receives the MIDI commands and plays the sounds according to how it is programmed.

2.1 Sound Mapping with the Tooka

Based on the feedback from the musicians playing the Tooka we made several modifications to the instrument. The changes included adding a fourth button, adding a bend sensor, adding thumb pressure sensors, and adjusting the musical mapping.

2.1.1 Button to Note Mapping

The Tooka button mapping remains the same as in the original Tooka [3] except that we arrange them with the white button at the top, followed by the new red and black buttons. The four black buttons (two per player) are used together for a range of 16 pitches. The octave is set with the two white buttons. In total, the musicians can control up to 64 button combinations with the four black and two white buttons. These combinations are mapped to MIDI note numbers.

We chose to map each player's white button to shift the pitch by one octave (in our current implementation, the four combinations correspond to a base note of C2, C3, C4 and C5). We use the other two black buttons that a player has for semitone offsets from the current octave. There are 16 different positions mapped to 14 semitones above the base note and two notes below allowing multiple fingering for the same note. Button order was selected in consultation with one of the musicians. This mapping was easily learned by the musicians and has many implications for how the musicians and audience perceive the effort towards playing music as described in Section 3.5.

The fourth button (red), called the capture/sustain button, was added to provide texture. Specifically, the fourth button captures the currently playing sound and sustains it as long as the button is held. The musicians can build up a range of notes to make a chord or drone against which to play melodic passages, or simply to build up a wall of sound. This is done by first, playing a note together. While the note is sounding, one player presses the red button to capture the sound. Then, a new sound may be added and the pair can be captured by the second player.

The capture/sustain algorithm is state sensitive, in that the player who most recently pressed a sustain button has sole control over the entire buffer of stored notes, and can end all sustained notes at once (by releasing the button). A single player cannot capture more than one note in a row, but must take turns with the other player to accumulate notes. We conceptualize this complex behaviour as the "stealing" or "passing back and forth" of captured notes.

Thus, the operation of the capture/sustain has been designed with three desirable characteristics:

1. The currently playing note can be captured and maintained as a background for new playing, retaining its original volume, pitch, and vibrato.
2. Notes can be continually layered, each with different tonality (currently eight is the limit, relating to the number of available channels on the MIDI module).
3. Coordinated turn-taking is required to build layers of notes.

Turn-taking presents a parallel with the Gray code button-pitch mapping of the other 3 buttons. This turn-taking is difficult to learn as it is easy to lose track of whose turn it is. This is predicted from the work of Sellen et al. [8] with respect to mode errors since with Tooka, the state of the capture mode can be changed by one player while the other is still holding down the red key. Thus, either one player doesn't realize they can lift their capture/sustain key or they may inadvertently lift it and the drone sustained notes stop. While this approach makes the instrument more challenging, going against usual HCI guidelines, it focuses on the relationship between the players requiring more communication between them.

Players can chose which fingers from which hand control the buttons. Choosing which hand to use and which fingers is a complex issue. The note buttons are grouped, as are the octave and capture/sustain buttons. This arrangement allows one hand to play within an octave while the othe selects the octave and capturing effects such as a drone. Each player chose differently.

From a theoretical perspective, Guiard's kinematic chain model [6], suggests using a grouping that allows the non-dominant hand to establish the context while the dominant hand plays within the context. Thus, note offsets and pitch bend should be played with the dominant hand. However, it is unclear what the octave key does. If playing within an octave, the non-dominant hand should control the octave, however, if playing a large pitch range, then the octave key doesn't establish the context, so should be played with the dominant hand. The capture/sustain establishes the background drone so fits well with non-dominant hand control.

What we observed is that players tended to alternate between one-handed and two-handed modes. As one musician noted, "I use my right hand (my non-dominant hand) except when I need extra help." As described in Section 3, players developed fingering techniques as they played.

2.1.2 *Air pressure*

Air pressure is mapped to the loudness of the sound approximating an effort-to-sound level map that a player experiences with a recorder.

2.1.3 Bend Sensor Mapping

We attached a 4.5" resistive bend sensor to the Tooka so that we could measure the bend angle between the two ends as shown in Figure 4. This allowed the musicians to work together to bend the tubes to adjust the pitch. This addition is essentially a simplified form of the *Pushka*, described in [3]. The bend sensor output maps to pitch bend of the current note being played by the white and black buttons It has no effect on any notes that are being sustained. (Though, if a pitch bent note is captured, the note and its bend are captured and sustained.)

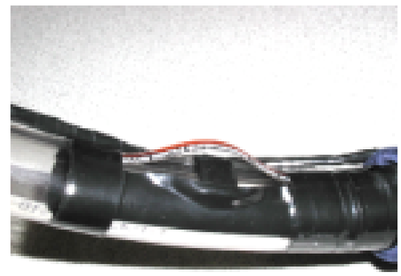

Figure 4: Tooka's Bend Sensor

2.1.4 Thumb Pressure Sensors

The thumb pressure sensors attached at each end map to vibrato. This effect is captured as well if a red button is pressed. See more on vibrato in section 3.

2.2 The Pd Patch

All the sensor data feed into an I-Cube which then feeds into a Pd patch that performs all the mapping and sends MIDI messages to a Yamaha MU-100 sound generator as shown in Figure 2. The software runs on a Mac G4 Powerbook.The Pd patch has a modular design with three main layers:

1. Input Layer: receives messages from the iCube. Outputs from this layer can easily be re-routed between modules in the Control-Mapping Layer.
2. Control-Mapping Layer: contains sub-patches embodying the input/output characteristics of each sensor type. The button-to-pitch sub-patch contains rewritable look-up tables, mapping four of the Tooka's buttons to note values and two of the buttons to octave values (see Section 2.1.1 for details). The breath-to-volume sub-patch performs a linear mapping from breath-pressure sensor values into MIDI channel volume values. The vibrato sub-patch performs a similar linear mapping from finger pressure to vibrato. The bend sensor sub-patch translates normalized bend-sensor values into pitch-bend values in semitones. We compensated for non-linearity in the bend-sensor voltage output by using a 2-D calibration curve that can be freely edited (see Figure 5).
3. Output Layer: formats and sends MIDI messages to the MU-100, and handles channel assignments and polyphony. The capture/sustain feature is implemented by taking advantage of the multi-channel capacity of the MU-100 MIDI module: at the moment a note is captured, the state of the current channel is 'frozen' and subsequent input is routed to the next empty channel.

The Pd patch is designed to support easy debugging and development of the Tooka. Incoming sensor data is visible in both numerical and graphical form, before and after calibration. An optional debugging switch enables data logging to the console. There is also a simulated Tooka input subpatch for performing sanity tests on the system, as well as a global configuration subpatch for adjusting constants such as base pitch and MIDI program number.

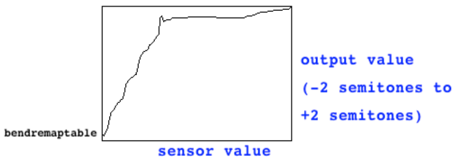

Figure 5: Graph to adjust pitch bend mapping.

3 MUSICIANS' EXPERIENCES

Given this was a new experience for the wind players, their initial response to the Tooka has been very positive. While the instrument provides interesting and some unusual problems for performance, the musicians seem to be finding solutions that contribute to the expressive potential of this system. This section discusses how the musicians currently deal with breath, finger, pitch bend, and sound capture coordination and as well as communication experiences.

3.1 Breath Coordination

One of the first lessons in breath control on the Tooka came when the wind players realized that they would be maintaining pressure levels rather than airflow. This meant that it wasn't necessary to blow very hard, but to gauge the pressure by sensing it inside the mouth, throat, and lungs. We suspected that the greatest degree of pressure control would be from the tongue. However, the wind players would have had to learn a new type of tongue movement, aiming to adjust pressure rather than create an attack. As a result, the musicians tended to use their diaphragm, throat, and cheek muscles for modulating the air pressure (and hence, volume) instead.

A number of other expectations were not met from the experiences with the musicians using their breath. First, the players only release air from the Tooka into their throat or out through the sides of their mouths and not through their nose. Second, most of the articulation was done with the player's fingers rather than breath, especially for faster passages. Finally, even though players can breathe while maintaining air pressure, this did not seem to be a preferred technique. Instead, the two musicians sometimes stop breathing and/or remove their mouth from the mouthpiece to breathe. The musicians take additional breaths on some occasions due to fatigue, on others, for expressive effect. The device does leak some air causing the players to constantly have to add air to keep the pressure up.

The musicians began looking for expressive ways to shape the sounds at about the time that they memorized their first scale pattern. They discovered how to create dynamics by adjusting the pressure inside the tube. A lower pressure creates a softer sound; a higher pressure creates more intensity. In this way, the two musicians can collaborate on note and phrase shape; however, they must be able to agree on the desired shape and intensity for the sound. The musicians use notation (such as shown in Figure 6) and discussion, and real time awareness and gesture to communicate these intensions. One drawback of the breath system is the difficulty in creating varied or quick rhythms through coordinating fingers with breath

Figure 6: Example of one type of Tooka song notation

articulations. On traditional wind instruments, these systems can be developed to a high speed. The tongue movements required for influencing the onset of sound on the Tooka did not seem to be natural for wind players in the beginning. Instead, they initiated sounds with the larger systems: cheeks, throat, and diaphragm. This, combined with the necessity of two-person collaboration, makes for a slower system overall. When the musicians want to play faster passages, those passages must be controlled with finger motion alone. In terms of breath attacks, the musicians can punch notes out, or approach notes gently, but they find it difficult to replicate the tonguing speed of a traditional wind instrument. However, the Tooka does provide its own distinct musical character, even if slower than a traditional wind instrument. Control over note shape is strong and effective on this instrument.

Additional expressive shaping occurs with the vibrato options. Vibrato can be approached in three ways on the Tooka, through the touch sensor, the bend sensor and through breath control. The breath control vibrato works for longer expressive passages. To create breath vibrato, players must cooperate on shifting the pressure inside the tube; therefore they must look at each other and feel the pressure inside their mouths and adjust it for expressive effect. This very intimate collaboration on expressive shaping of a note can be musically very effective. Finally, the touch sensor and bend sensor vibrato are discussed in 3.2 and 3.4 respectively.

3.2 Finger Coordination

During the first and second practice sessions, the musicians used fingering charts from the original Tooka [3]. The next step was to create a four-octave chromatic scale fingering chart like the ones typically seen for traditional wind instruments. From this chromatic fingering chart, the musicians figured out scale and chord patterns. At the same time, they worked with finger patterns to create more abstract melodic lines based on finger motion.

It is interesting to note that the musicians find both the abstract sonic possibilities and the traditional 'virtuosic' possibilities to be equally pleasing on this instrument. In fact, one of the highlights of practice sessions so far was the moment they were able to recall a scale without using a fingering chart. This scale, the raga "Mayamalavagowla" provides the musical backdrop for one of their first compositions.

Once the scale was learned, the musicians could then discover the subtleties of finger articulations. The precision of combined finger movement is what creates the quality and character of an articulation sound on the Tooka. This effect is both pleasing and challenging, and contributes to the virtuosic potential of the instrument. Because the articulation sound is decoupled from the breath sensor (it is coupled with finger buttons), there are ways to manipulate sounded notes separately from their articulations to create unique effects.

If the players want to play a scale or melody, they must communicate clearly on which notes are to be played when. They must move their fingers at exactly the same time. For most trained musicians, this is not too difficult. Still, even trained musicians need to be very aware of the expressive intentions of the other player on the Tooka. This heightened need for mutual awareness is one of the collaborative features of this instrument. Finger motion influences the articulation, and when fingers do not move together, rough spots can occur in the melodic line.

The touch sensor for adding vibrato to the current note improves the expressive quality in a melodic line. It is most useful for adding color or emphasis to a short note in a melody. This feature adds to expressive potential in faster passages where breath and/or bend vibrato are too cumbersome.

3.3 Capture/Sustain Feature

After the first few practice sessions, the musicians requested an additional mechanism for adding texture. So, texture was added by way of the capture button on the Tooka. This feature allows the musicians to sustain sounds while playing other sounds simultaneously. So, a pedal note, chord, or drone can be held while a melody or other abstract pattern is being played simultaneously. The musicians first used this feature to sustain drones for a backdrop improvisation on a raga. Later, they used the capture/sustain feature for other, more abstract effects.

Sometimes the musicians use the capture button to surprise each other by capturing a sound or adding another layer to sound backdrops while performing. Both players have control over this feature and can manipulate the sound environment this way. A captured sound can be ended or added to by the second player. Surprisingly, this feature created a whole new musical world for the players. Now they can accompany their own combined improvisations. This feature added much musical depth to the system.

Currently, sounds remain exactly as they were when captured. However, the musicians have asked for additional control over this feature; they would like to drop notes or change the intensity of the captured sound.

3.4 Pitch Bend Coordination

The bend sensor was added after the sound capture feature to help the musicians adjust the pitch while playing simultaneous notes. When the musicians bend the Tooka, the pitch goes up; when they pull back to straighten the Tooka, pitch goes down. With this feature, notes can be approached from above or below, and given a pitch shape.

As mentioned earlier, vibrato can also be accomplished using the bend sensor. This is the slowest and most awkward vibrato, but it has dramatic expressive potential because the movements are obvious and very connected to the sound.

3.5 Tooka Communication

Our primary motivation around designing a two-person instrument was to explore intimate, engaged experience around players, instrument and audience. We have recognized that the experience of the Tooka players have some similarity and difference from the experience of traditional one-person instrument players. Because of direct mapping of tone and pitch bend control, Tooka players quickly notice that they have certain control over the sound, which increases the intimacy between the players and instrument. It is experientially as engaging as any other successful musical instrument. The difference is that neither of the players can engage themselves to the instrument independently. From the simple level of not being able to practice alone, playing Tooka means you have to communicate with another player and, thus, intimacy with the instrument occurs only through engagement with the other player. In a sense, the other player becomes a part of the instrument and each player starts communicating with this intelligent, sensitive 'live' instrument. In other words, playing Tooka is a new way of communication between two people. The Tooka plays the unique role of communication tool through sound not only as musical instrument. Players feel satisfaction through play even without audiences since the other player also plays a role of primary audience. In this way, Tooka indicates a new meaning and purpose of musical instrument and it can be also used for educational purpose or therapy.

Tooka also suggests a new concept of collaborative music. Traditionally collaborative music has the style of "duo", "trio", "ensemble", etc. Tooka experience is very different from those types of collaboration. We have noticed the clear difference during our improvisation session with other traditional musical instruments, (piano, harp, violin and saxophone). Inside a large ensemble of different instruments, Tooka players formed a sub-unit of communication among the whole ensemble unit. This influences the dynamic of the ensemble, which suggests a new possibility of collaborative musical expression through various group dynamics enhanced by the Tooka.

The Tooka is an intriguing instrument also from the perspective of the audience. Usual duets or ensembles provide coordinated harmony or music to the audience. With the Tooka, each single note is collaboratively shaped out sound, and bodily effort of two players coordination is visible. Just as Japanese puppet theater (Bunraku) creates one imaginary puppet character through collaboration of three puppet masters, Tooka creates one sound which is neither the intention of player A nor player B. What an audience sees is effort of communication, and what it hears is the expression that emerges through two persons' interaction.

4 FUTURE DEVELOPMENT

We are currently user-testing the Tooka through practice sessions and performances, including improvisation with different instruments. For the future development two directions are possible; instrument improvement and improvement/invention of the technique/style of Tooka playing.

4.1 Improving the Instrument

The current version of the Tooka uses a MIDI sound module as the sound source. We are interested in designing an original Tooka sound for this instrument to maximize the musical expressiveness. We have to find the right tonality to match the form and feel of the instrument better. We are also interested in adding several more features to improve the ability to shape the sound collaboratively and give more dynamic to the sound performance.

First of all, we are in process of adding an accelerometer on Tooka to detect the tilt motion of the instrument. One of the musicians is experienced with spatialized sound, thus we intend to use this to spatialize the sound. As an electric instrument, Tooka sound output is through loud speakers, allowing us to use the performance space as a part of the musical expression and element of composition. We think the sound spatialization visually connected with the motion of two players will be effective.

The second additional development will be adding sensors on the tube to detect torque motion and control the sound. Since the current version of the Tooka has a bend feature (pushing motion) similar to *Pushka*, we would like to try exploiting torque motion to add more variation in collaborative sound modification. We are also interested in combining the concept of *Pullka* [3] by using a string for modifying the captured sound layers to give more freedom to the players. The current version of Tooka doesn't have controls for captured sound. The placement of string(s) and consistency with other coordinated play remain to be done.

The current version of Tooka already has a good range of expression through breath, but even finer tuning may give the players a better feeling of control over sound, providing a more intimate experience. Thus, we are planning to combine three pressure sensors with different sensitivity to obtain maximum dynamic range for finer expressive breath control.

4.2 Improving Performance Technique and Gesture

As a new instrument, the performance technique of Tooka is still under refinement. We have encountered several primary issues around techniques during first practice sessions. For example, understanding how the instrument is held and which finger is assigned to which button is important. A more complex technique coordinates the breath and timing to generate successful musical expression. We are planning to monitor the practice of this instrument over the years to figure out the appropriate and most effective performance technique around this instrument. Especially, 1) developing a notation system for composition 2) developing breath technique 3) developing gesture/signal systems for better coordination. These techniques are critical for improving the musical expressiveness of the Tooka.

4.2.1 Gesture Research with Tooka

The Tooka provides a rich environment for the study of gesture in collaborative music making. Because both players have intimate connection with the sound result, they must learn to move in ways that indicate their musical intention clearly to the other performer.

We will be using the Tooka to study the ways that these musicians use gesture to indicate their musical intentions and to what extent those gestures are predetermined or natural. Our goal is to gather data on the movements of both players using Optotrak motion capture and sound recording. Initially, we will look for the kinds of movements that indicate musical intention and the kinds of movements that correspond directly to sonic expression. Not all motions will influence sonic output on the Tooka. For instance, once a note is captured, it remains the same regardless of waving hands or feet. However, movement of the torso up and down, head motion, and facial expression may change the pressure in the tube, and result in sonic changes for a sounding note (not captured). Another example of expressive gesture occurs as the musicians rise in pitch. It is not necessary for the players to blow harder; the sounds speak with the same amount of pressure in both the low and high registers. But the musicians find themselves gesturing as if the instrument required more air for high notes. These observations will prove interesting for gesture research in music performance.

5 SUMMARY

The musicians are, overall, quite pleased with the flexibility and expressive potential of this wind instrument. They have managed to find ways to collaborate expressively on traditional melodies, as well as abstract sonic environments. Additionally, they have used the instrument in improvisations with musicians playing traditional instruments, saxophone, violin, harp, and piano. They have also begun working on a range of music styles, from gagaku, to raga, to classical preludes of Hotteterre. The musicians have also begun requesting new kinds of sonic outputs like street sounds, environmental sounds and specially designed Tooka sounds.

When we created Tooka, our focus was on exploring how the intimacy between two players could be expressed through sound. Through musicians playing it, Tooka has evolved into an exciting new musical instrument, accepted by musicians, with many expressive capabilities that reaches into new means of communication between players, ensembles and audiences.

6 ACKNOWLEDGMENTS

Our thanks to Florian Vogt, Edgar Flores, Kuang Tien, Brian Fisher, Giorgio Magnanensi, Eric Vatikiotis-Bateson and members of the HCT and Psycholinguistics Laboratory and musicians from the UBC School of Music for their assistance. This work is supported by MAGIC, POLA Art Foundation, Japan and the CRC and NSERC, Canada.

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