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Measuring tongue and finger coordination in saxophone performance

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ABSTRACT

When playing wind instruments the fingers of the two hands have to be coordinated together with the tongue. In this study, we aim to investigate the interaction between finger and tongue movements in portato playing. Saxophone students played on a sensor-equipped alto saxophone. Force sensors attached to 3 saxophone keys measured finger forces of the left hand; a strain gauge glued onto a synthetic saxophone reed measured the reed bending. Participants performed a 24-tone melody in three tempo conditions timed by a metronome in a synchronization-continuation paradigm. Distinct landmarks were identified in the sensor data: A tongue-reed contact (TRC) occurred when the reed vibration was stopped by the tongue, a tongue-reed release (TRR) at the beginning of next tone, and in the finger force data a key-bottom contact (KB) at the end of the key motion. The tongue-reed contact duration (from TRC to TRR) was 34.5 ms on average (*SD* = 5.84) independently of tempo condition. Timing accuracy and precision was determined from consecutive TRRs. We contrasted tones that required only tongue impulses for onset timing to those that required also finger movements. Timing accuracy was better for combined tongue-finger actions than for tongued timing only. This suggests that finger movements support timing accuracy in saxophone playing.

I. INTRODUCTION

Several instruments require the coordination of both hands to produce a musical sound (Baader, 2005). In wind instruments, the fingers and the tongue have to be coordinated. Phrasing techniques on saxophone and clarinet, require tongue impulses to the reed to initialize tone onsets while a change of fingerings modulates the pitch (Liebman, 2006; Koch 1989).

Articulatory motion of the tongue during speech has been investigated from a clinical point of view by using x-ray, ultrasonic (Sonies, 1981) and magnetic resonance imaging systems (Uecker, 2010). Strain gauge based sensors, attached to musical instruments have been successfully used to measure bow forces during violin performances (Young 2002, Schoonderwaldt & Demoucron, 2009) and mouthpiece force while trumpet playing (Bertsch & Mayer, 2005).

Timing of fingers during expressive musical performance has been studied extensively in piano playing due to the fact that MIDI keyboards provide easy access to timing information of each played note (Repp, 1996). Motion capture systems have been used to gain additional information as finger trajectories and finger acceleration curves (Goebl & Palmer, 2008). A similar method was used to investigate temporal accuracy in clarinet performances (Palmer et al., 2009). Bow-finger synchronization in violin performance was investigated by the use of motion capture recordings and showed that it varied about 50 ms from perfect simultaneity (Baader, 2005).

The present study provides a first account on simultaneous recording of finger actions and tongue impulses to the saxophone reed, to (1) quantify synchronization between finger and tongue actions and (2) to investigate timing differences between fingered and not fingered portato sequences.

II. Method

A. Participants

Seven male and three female (N = 10) graduate saxophone students (mean age = 21.5, range = 18–26 years) with an average of 10.5 years (4.5–14 years) of saxophone instructions participated in the study. All participants were classical saxophone students from the University of Music and Performing Arts Vienna, joining the program between 0.5 and 7 years ago. The average amount of time spent practicing the saxophone was 2.1 h per day (*SD* = 0.9). Participants were paid a nominal fee.

B. Stimulus Material

A 24-tone melody was created for the experiment that consists of two parts (Fig. 1): The first part (note number 1–8) is a tone repetition, not requiring any fingerings. The notes 9 to 24 require a sequential depression of keys by left-hand fingers: Index finger (2), middle finger (3), and ring finger (4) and release of all three fingers. All participants played on an E-flat alto-saxophone; thus, it sounds a major sixth lower than notated. All notes had to be played in portato articulation, so that the melody is played with a continuous air-stream, every new tone is initialized by a tongue impulse to the reed.

Figure 1. 24-tone melody in E-flat notation

C. Experimental setup

The experimental setup consists of a sensor-equipped alto saxophone, a metronome and a recording device.

1) Keys

Standard industry force sensors (Flexiforce, 1N) were attached to the pearl of 3 saxophone keys with Petro Wax (PCB Piezotronics) to measure forces of left-hand index, middle and ring finger (Fig. 2). The sensing area has a diameter of 9.53 mm covering the key-pearl and a thickness of 0.208 mm.

2) Reed

A strain gauge (2 mm, 120 Ohm) was glued onto a synthetic saxophone reed to measure its bending during performance (Fig. 2). The strain gauge was build as one resistor in a

a) **b)** **c)**

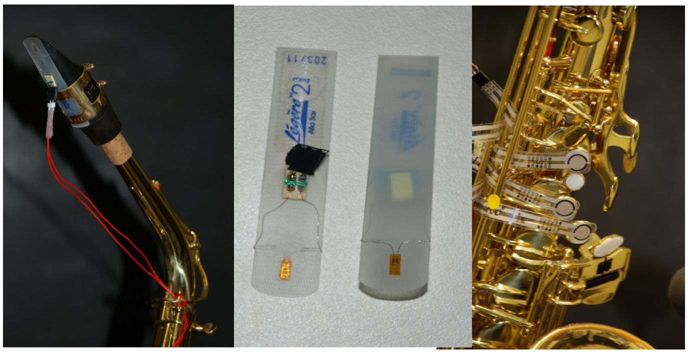

Figure 2. a) Mouthpiece with Sensor Reed b) 2mm Strain Gauge glued on plastic reeds c) Force sensors on keys

Wheatstone bridge, the gauge-factor signal was amplified (TI, INA 126) to a range of 0–5 V. The electronics for all 4 sensors were packed on a small card, powered by an external laboratory (5V DC) power supply. The circuit box was attached to the bottom end of the saxophone. The four outputs were connected by BNC cables to National Instruments (LabView) hardware for 16 bits analog to digital conversion at a sampling frequency of 11025 Hz. A microphone (AKG C414) was placed one meter away from the player. In total, 6 channels were recorded digitally onto hard disk, containing four channels of sensor data, the sound from the microphone and one channel with the metronome click.

D. Procedure

In the beginning of the experiment each participant had to choose one synthetic sensor reed out of four different reed-strengths (Légère: 2, 2.25, 2.5, 2.75). The players were allowed to use their own mouthpiece and got a 5 minute warm-up time, to practice the melody with the metronome in slow tempo. A Korg metronome provided the synchronization signal on each quarter-note beat.

In the beginning of a trial, the players synchronized with the metronome for 2 repetitions of the melody. After the metronome stopped they continued in the same tempo until the melody was played 6 times. The given tempi were 120 (slow), 168 (medium) and 208 beats per minute (fast). Each trial was played twice in the same tempo condition. Trials were blocked by the tempo condition ordered from the slowest to the fastest. In total 870 tones were recorded for each participant.

E. Data processing

1) Reed

Distinct landmarks were identified in the reed data: A tongue-reed release (TRR) occurred when the tongue was removed from the reed at the beginning of a tone. A tongue-reed contact (TRC) occurred at tone ending, when the reed vibration was stopped by the tongue (Fig. 3).

Reasoned by the characteristics of the reed signal, which contains high frequency oscillation during sound production, the signal required smoothing (low pass, 15hz) to eliminate unneeded signal extrema. Displacement of the reed caused by the tongue was then detected as local extrema in the smoothed signal. Through this method 97.4% of the expected number of played tones were identified. These points were additionally confirmed by thorough ocular inspection. In a second step the landmark positions were refined by identifying close-by peaks in a less smoothed (low-pass, 130 Hz) signal.

2) Keys

The finger press on the saxophone key is stopped, when the key cushion closes the tone hole. This usually causes a short peak in the force curve. Following Goebl & Palmer (2008), those peaks were identified as key-bottom (KB) landmarks. We detected them as the zero-crossing before the maximum extrema in the derivate of the smoothed (low-pass, 280 Hz) signal (Fig 3). KB landmarks were expected in a 80 ms window around TRRs.

Extraction of time-relevant information from the force signal was more difficult and less successful than with the reed signal. Only 46.34% of all expected fingerings were detected due to the fact that the desired peak was not always found clearly in the force data. Possible reasons will be discussed later.

III. Experimental results:

1) Timing accuracy:

Interonset intervals (IOIs) were defined as the time interval between two consecutive TRR landmarks. Calculated IOIs during synchronization phase were very close to metronome rates; at slow tempo IOI = 249.4 ms (metronome = 250 ms); medium IOI = 178.9 (given = 178.6 ms); fast IOI = 144.3 (given = 144.2 ms) showing that saxophonists could synchronize well with the metronome.

We computed the timing error $(IOI_{obs} - IOI_{exp})/IOI_{exp}$ which describes the relative deviation from the given tempo. A two-way repeated-measures ANOVA by tempo condition (IOI 250 ms, 178.6 ms, 144.2 ms) and synchronization condition (with vs. without metronome) indicated a significant main effect of tempo ($F(2, 18) = 21.488$, $p < .001$) as well as a significant interaction of tempo and synchronization condition ($F(2, 18) = 25.241$, $p < .001$). In synchronization with the metronome, the average signed timing error was close to zero ($M = –0.0022$, $SE = 0.0025$) compared to the continuation phase ($M = 0.0176$, $SE = 0.0070$). The mean timing errors during continuation phase increased as the tempo became faster (slow tempo = –0.0145; medium = 0.0184; fast = 0.0488) suggesting that it was difficult for the players to keep the introduced tempo. The black line in Figure 4a depicts the trend to play too fast in slow tempo and to slow down at fast playing speeds when there was no metronome orientation.

The variability of the IOI's was calculated by the coefficient of variation (CV, defined as $Sd_{ioi}/Mean_{ioi}$) for each melody phrase and tempo condition. The same two-way ANOVA was calculated for the CV's and revealed a significant main effect of synchronization condition ($F(1, 9) = 14.057$ $p < .01$) as well as a main effect of tempo ($F(2, 18) = 9.1493$, $p < .01$), but no significant interaction. Figure 4b depicts the loss of timing precision as the tempo became faster.

2) Duration of tongue-reed contact in portato playing

Next, we investigated for how long the tongue touches the reed in between two tones. For that we subtracted TRC times from TRR to get tongue reed times (TRt). A one-way repeated-measures ANOVA on TRt by tempo condition showed no significant effect of tempo. The average duration in mean was 34.5 ms ($SD = 5.84$). This time independent break between two tones gains more weight with faster tempi (slow = 13.8 %; medium = 19.3 %; fast = 23.9 %).

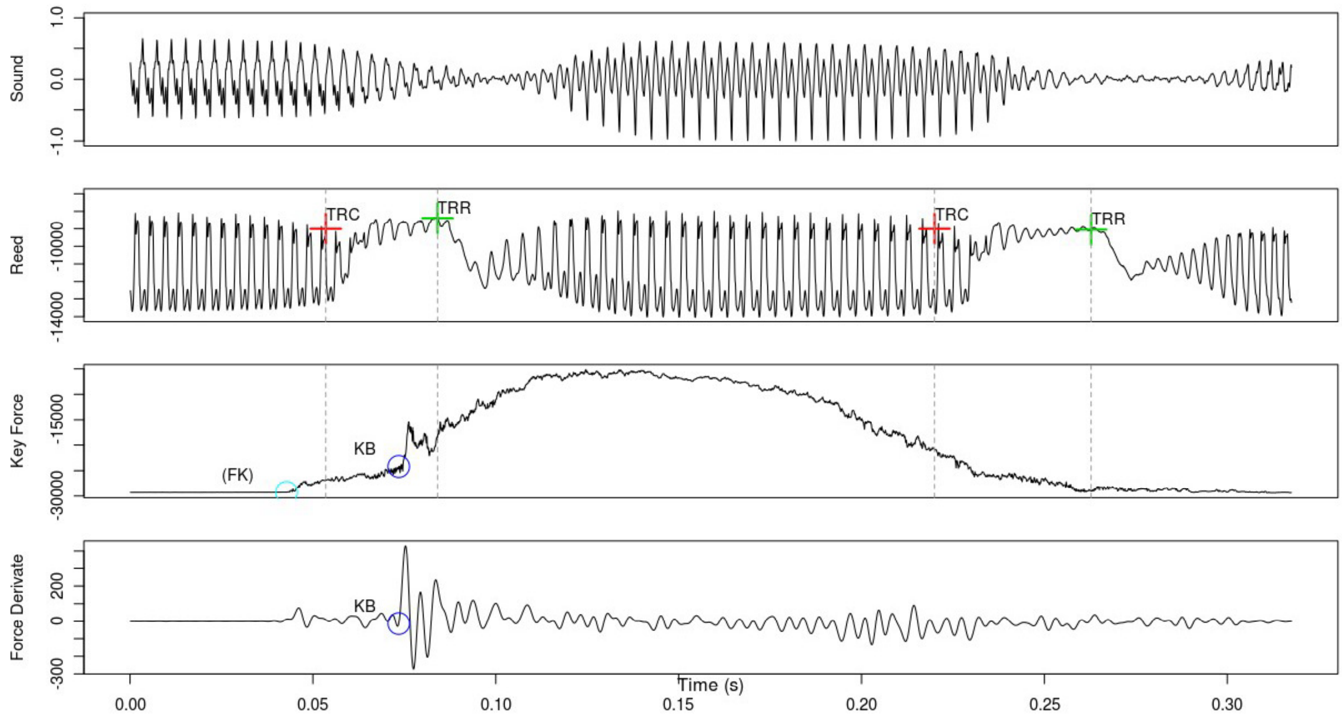

Figure 3. Recorded data for one tone: Audio Signal from 1m distance (top panel), Sensor Reed (middle panel) and Key Sensor and its derivate (bottom panel), is shown. Tongue-reed (TR) landmarks are indicated by a cross in the reed signal and key-bottoms (KB) by circle in the force data.

3) Coordination of tongue and fingers

We calculated the key-bottom to note-onset time distance (TRR – KB). The mean of 1.33 ms (*SD* = 8.17) indicates that on average keys are pressed very shortly before note-onsets are initialized by the tongue. There was a considerable inter-subject variability, which requires more detailed investigations. Some subjects force sensor data did not obtain the signal quality to identify the required fingering landmarks. The resulting missing data did not allow to do further reliable statistics at this point.

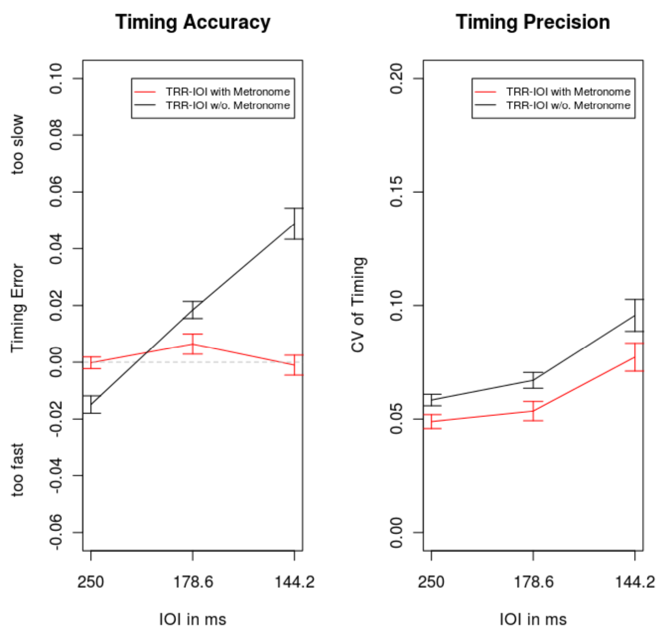

Figure 4. a) Timing accuracy for synchronization phase (red) and continuation (black). b) Timing Error increases with tempo.

4) Timing modality between tongued tones and tones with tongue impulses to the reed with fingerings

We now focus on the inner melody differences and its impact on timing accuracy and precision in the continuation phase.

The first 8 notes of the melody is a tone repetition, which is played (and thus timed) by the tongue only. The second part of the melody requires tongue actions synchronized with the fingerings. A one-way repeated-measures ANOVA on timing error revealed a main effect of timing modality ($F(1, 9) = 9.33$, $p < .05$). The mean timing error for note-repetitions ($M = 0.028$) was much higher than for fingered tones ($M = 0.007$). This leads to the assumption that combined tongue and finger movements support timing accuracy. Even though the same ANOVA on CV did not reveal significant effects of timing modality ($F(1, 9) = 3.01$, $p = .12$), there was a trend of timing precision to increase slightly with the combination of tongue and finger movements (CV note-rep. $M = 0.080$; CV fingered $M = 0.063$) (Fig. 5).

IV. Discussion

Precise timing is needed when performing music alone or in a group. In several articulations saxophone players initialize note-onsets with their tongue. We investigated the coordination of tongue impulses to the reed and finger force on saxophone keys.

Although the tongue sets the note-onsets, we could show that fingerings play an important role in saxophone timing accuracy and precision. It would be of interest to compare this along different phrasing techniques (staccato, legato) and through different playing-styles in future research.

This was a first study that successfully used strain gauge sensors on saxophone reeds to extract information about

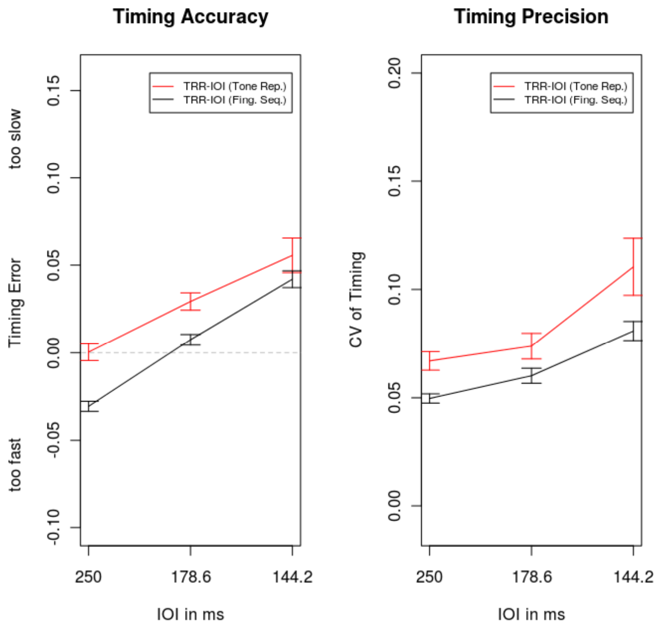

Figure 5. Timing accuracy (left) for note repetition (red) and fingered notes (black). Fingered notes were played more accurate and showed a lower IOI variability (left).

articulation during performance. We decided to use synthetic instead of wooden reeds because of their stability and hygiene, but some players complained about the different playing feel, as they usually practice on wooden reeds.

The usage of standard industry force sensors on the saxophone keys made it difficult to obtain the time-relevant data from the fingerings. The signal quality was considerably affected by angle and position at which the finger touches the sensor. Little variations to one either the other side changed the signal quality significantly. In future work, special designed sensors for each individual instrument, made out of low temperature co-fired ceramics, will improve these force measurements.

Such multi-sensor saxophones deliver valuable insights into the complex interaction of tongue and finger actions. This method may be applied also to clarinet and other woodwinds.

V. Acknowledgement

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REFERENCES

Baader, A., Kazennikov, O. & Wiesendanger, M. (2005). Coordination of bowing and fingering in violin playing. *Cognitive brain research* 23(2-3) (pp. 436–443).

Bertsch, Matthias; Mayer, A. (2005). A New 3D Transducer for Measuring the Trumpet Mouthpiece Force. *Proceedings of the Forum Acusticum Budapest 29.08. – 02.9.2005*, (pp. 23–30).

Goebl, W. & Palmer, C. (2008). Tactile feedback and timing accuracy in piano performance. *Experimental Brain Research* 186(3) (pp. 471–479).

Koch, E. (1989). *Schule für Klarinette in B: Deutsches und französisches System.* Leipzig: Deutscher Verlag für Musik.

Liebman, D. (1989). *Developing a personal saxophone sound.* Medfield: Dorn Publications.

Palmer, C., Koopmans, E., Loehr, J. D. & Carter, C. (2009). Movement-related feedback and temporal accuracy in clarinet performance. *Music Perception* 26(5) (pp. 439–449).

Repp, B. (1996). The art of inaccuracy: Why pianists' errors are difficult to hear. *Music Perception* 14 (pp. 161—183).

Schoonderwaldt, E. & Demoucron, M. (2009). Extraction of bowing parameters from violin performance combining motion capture and sensors. *The Journal of the Acoustical Society of America* 126 (pp. 2695–2708).

Sonies, B., Shawker, T., Hall, T., Gerber, L. & Leighton, S. (1981). Ultrasonic visualization of tongue motion during speech. *The Journal of the Acoustical Society of America* 70(3) (pp. 683–686).

Uecker, M., Zhang, S., Voit, D., Karaus, A., Merboldt, K. & Frahm, J. (2010). Real-time MRI at a resolution of 20 ms. *NMR in Biomedicine* 23(8) (pp. 986–994).

Young, D. (2002). The hyperbow controller: Real-time dynamics measurement of violin performance. In *Proceedings of the 2002 Conference on New Interfaces for Musical Expression* (pp. 1–6).