COMPARISON BETWEEN THE MEASURED AND PLAYED INTONATION ON FOUR E-FLAT CLARINETS IN THE ALTISSIMO REGISTER

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ABSTRACT

In this paper, two experiments were conducted to compare the intonation in the altissimo register (C#6–C7) on four german Eb-clarinets. In order to perform the experiments a fingering chart was created including twelve main fingerings with up to eight alternative fingerings (68 fingerings in total). As a first method, a professional clarinetist recorded the 68 fingerings in an anechoic chamber under controlled performance conditions. As a second method, input impedance measurements (BIAS) were done to gain objective data of the instrument's build quality, independent of a player. From the results of the first experiment, the tones of the altissimo register were subdivided into three groups of tones: In the first group (C#6–F#6) the main fingerings resulted in a correct intonation. In the second group (G6–G#6), alternative fingerings were proposed which helped to correct the intonation. In the third group (A6–C7), it was impossible for the professional performer to play the targeted pitches. A comparison of the intonation curves from the audio recordings and from the input impedance measurements indicated contrary trends. It remains an open question, which factors are actually limiting the playing range of the instruments. It is hypothesized that both, the low input impedance peaks for the altissimo notes and the reed's natural frequency may limit the playing range of the instrument.

1. INTRODUCTION

The Eb-clarinet belongs to the family of the high clarinets and does sound a minor third higher than written [1, 2]. The instrument often carries the top line in unison with the piccolo, first violins or solo alone and adds strength and brilliance to the notoriously weak upper register of every orchestra [3]. Many instrumentation and orchestration books [5, 6, 7] give a smaller tonal range for Eb-clarinets (E3–G6), in comparison to Bb-/Ab-clarinets (E3–C7, [8]). Composers frequently use the Eb-clarinet in the altissimo register [1, 9], but tend to ignore the range limit of G6 [10]. Playing on the Eb-clarinet is more difficult than on Bb-clarinets and many players [2, 3, 4, 8, 11, 12] reported intonation problems (being too flat in pitch) in the altissimo register. In such a case, audio recordings might help to better understand which tones are too flat.

The intonation in the altissimo register is mainly influenced by three factors.

First, the player can correct the pitch with his embouchure (lip pressure, blowing pressure or vocal tract configuration, [13, 14]). Larger deviations form a correct pitch can only be compensated by using alternative fingerings instead of main fingerings. An advantage of using alternative fingerings is that the player can maintain a constant embouchure which is not determined to one specific instrument. This allows an easier switch between different clarinets. Nevertheless, the player has to learn different fingerings which are sometimes difficult to apply in fast musical sequences. Numerous fingering charts exist in clarinet schools [15, 16, 17] and in the internet[1] which facilitate to correct the intonation in the altissimo register for the german clarinet system. Unfortunately, these fingering charts propose other main and alternative fingerings, especially in the altissimo register. It is planned to design a new fingering chart with main and alternative fingerings based on their frequency.

The second factor is the quality of the instrument (geometry, mouthpiece characteristic, reed characteristic). Thirdly, the environment (temperature, humidity) has to be taken into account [18]. However, this paper focusses on the player and the quality of the instrument.

Input impedance measurements on wind instruments have been shown to be a reliable method to characterize the objective quality of an instrument, independent of the player. Since now, Bb-clarinets were measured with the mouthpiece, using an adaptor for the input impedance measuring head [19]. Alternatively, mouthpiece and instrument body can be measured together or measured independently and combined later [20]. Input impedance measurements on Eb-clarinets could detect possible problem tones.

The clarinet [18] vibrates with modes that are odd multiples of the fundamental frequency (see figure 1) and tones are excited at high input impedance peaks. The 2^{nd} mode of oscillation has a frequency three times that of the fundamental, musically an octave and a fifth. The modes [18] of an input impedance curve of a clarinet can be subdivided into three registers. Depending on the fingering, the first mode excites tones between E3–A#4 (chalumeau register), the second mode tones between B4–C6 (clarion register) and the third and higher modes tones between C#6–C7 (altissimo register). Table 1 shows the subdivisions of the modes into three registers.

Mode	Tonal range	Register
Mode 1	E3–A#4	chalumeau register
Mode 2	B4–C6	clarion register
Mode 3 and higher	C#6–C7	altissimo register

Table 1: The modes of the input impedance curve of a clarinet can be subdivided into three registers.

However, nobody has so far assigned the main fingerings of the altissimo register to the respective modes.

[1] www.hueyng.de; timeforclarinets.de; klarinette-lernen.de; klarinette24.de

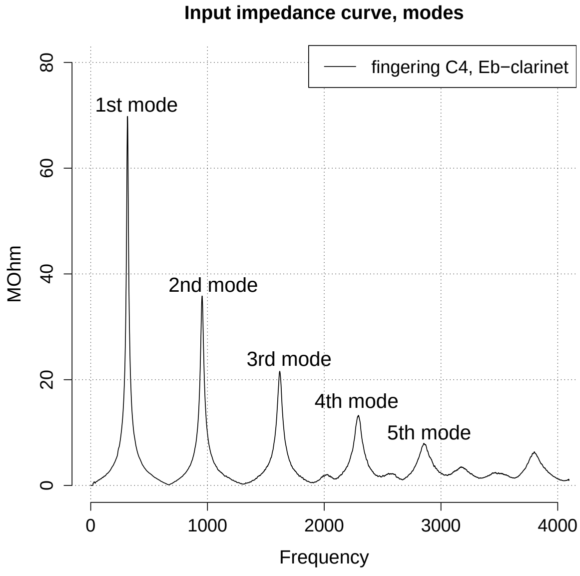

Figure 1: An input impedance curve can be subdivided into several modes.

2. AIMS

The author aims to design a new fingering chart with main and alternative fingerings, based on their frequency. In order to compare the played and measured intonation on four Eb-clarinets, audio recordings and input impedance measurements are foreseen. Better fingerings will be proposed for problem tones. Furthermore, the main fingerings of the altissimo register will be assigned to modes.

3. METHODS

First, a new fingering chart was designed to perform two different experiments on four Eb-clarinets (see table 2). In the first experiment the author recorded the pitch of 68 fingerings. In the second experiment main and alternative fingerings were measured through input impedance measurements.

Name	Instrument maker	Type
FH	F. Hammerschmidt	FH 11
OH	O. Hammerschmidt	16F
UE	A. Uebel	Eb
WH	H. Wurlitzer	120S

Table 2: Names, instrument makers and types of the four different Eb-clarinets which were used in the experiments.

3.1. Fingering chart

3.1.1. *Procedure*

A new fingering chart with 12 main and 56 alternative fingerings (4–8 alternative fingerings per main fingering) was created based on their frequency, which is a collection of a master thesis [19], different clarinet schools [15, 16, 17] and online charts[2]. The fingering chart was designed using Inkscape [21].

[2]www.hueyng.de; timeforclarinets.de; klarinette-lernen.de; klarinette24.de

3.2. Audio recording

In this experiment a professional clarinetist (17 years experience, author) played the tones of the altissimo register (12 main fingerings, 56 alternative fingerings) on four Eb-clarinets in the anechoic chamber.

3.2.1. *Equipment/Setup*

The experimental setup consisted of a measuring microphone (RG-50, by Roger), a metronome (KDM-1, by Korg Inc.), headphones and a professional hard disk recording device (by RME, 44 kHz, 32 Bit). The same Bb-clarinet reed was used for all recordings (White Master: German Cut, Reed Strength: 3 1/2, cut at the end to fit on the smaller mouthpiece lay) with a mouthpiece by MAXTON (material: PMMA).

3.2.2. *Procedure*

For each instrument, 12 tones were recorded with up to 8 alternative fingerings (68 fingerings in total). Each tone was played for three seconds with a break of one second. A metronome click (60 bpm) on open headphones (by AKG) was used for tempo orientation. The author played all tones with the same embouchure configuration (high lip pressure, high blowing pressure, high tongue position, miming ”ee”) and used an embouchure aid (paper over the lower teeth) to avoid lip pain. The audio recordings were loaded into Sonic Visualizer and the performed pitch was analyzed using the ”Aubio Pitch Detector” plugin (Version.1.9; Pitch Detection Function Type: Spectral Comb). The raw data (fundamental frequencies) was imported into R-statistics to calculate the pitch for each note to the equal tempered scale and for further analysis.

3.2.3. *Results*

In the first analysis the pitch of the main fingerings were investigated. Figure 2 shows that the pitch of the main fingerings can be subdivided into three groups.

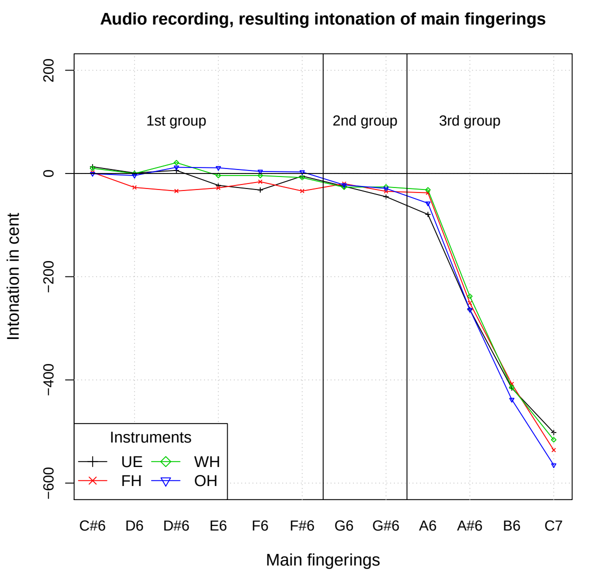

Figure 2: The pitch analysis of the altissimo tones showed that the main fingerings can be subdivided into three groups.

In the first group the tones C#6–F#6 were close to a correct pitch. In the second group the tones G6 and G#6 caused too flat tones on all Eb-clarinets and in the third group (A6–C7) the main fingerings produced tones, which were more than a halftone too flat. Consequently, in a second analysis the alternative fingerings of G6 and G#6 (second group) were observed to find fingerings towards best intonation. Figure 3 shows that an alternative fingering (G6Fing2, red) was able to correct the pitch offset for G6.

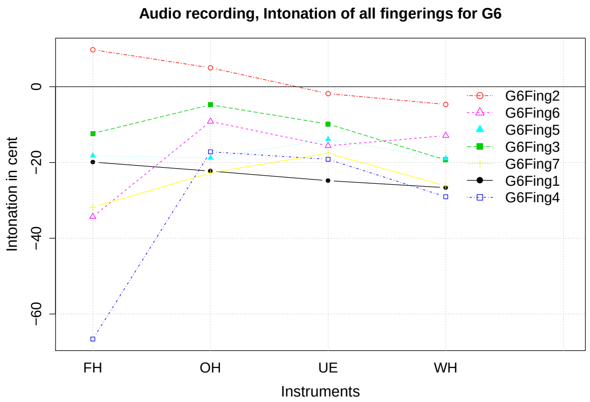

Figure 3: The pitch analysis of G6 showed that an alternative fingering (G6Fing2, red) helped to correct the pitch.

The same was the case for the tone G#6 (see figure 4), where the alternative fingering (G#6Fing5, cyan) helped to correct the pitch. The fingering G#6Fing5 was chosen as the best fingering, because the "UE" Eb-clarinet was close to a correct pitch. On the remaining three instruments (FH, OH, WH) the player can easily lip down a too sharp pitch with his embouchure. Input impedance measurements might help to understand the influence of these alternative fingerings.

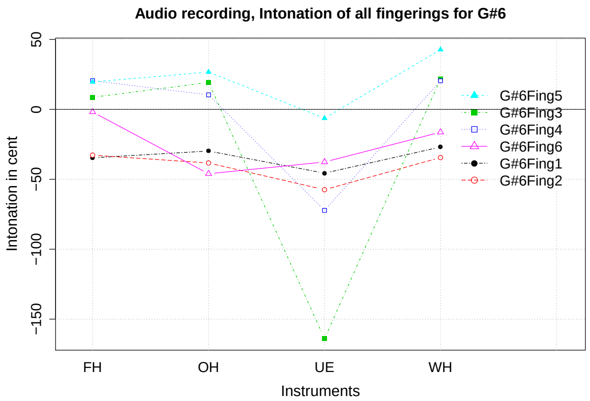

Figure 4: An alternative fingering (G#6Fing5, cyan) helped to correct the pitch for G#6.

However, further analysis of alternative fingerings of the tones A6–C7 showed that the pitch could not be corrected by using alternative fingerings.

3.3. Input impedance measurement

3.3.1. Equipment/Setup

The technical set up for the input impedance measurement (BIAS[3] Version 7.1, by ARTIM) consisted of the measuring head (Nr. 206S) held by a spring attached to a microphone stand, triggered by a foot switch (see figure 5).

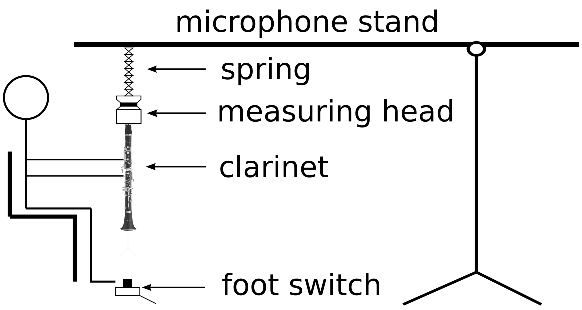

Figure 5: Measuring method using a microphone stand with a spring to reduce the weight of the measuring head and the instrument for the player.

This method reduces the weight of the instrument and the measuring head for the player and allows to measure the four Eb-clarinets with a natural posture. A foot switch helps to trigger the measurement after positioning the fingerings. The mouthpiece was replaced by a tube (14 mm inner bore, 58 mm length) to allow an easy exchange of the instruments and to calibrate the inner volume. The inner volume was calibrated with inlays of 6 x 1 mm to be equal to that of an Eb-clarinet mouthpiece. Figure 6 shows the cross section of the BIAS measuring head.

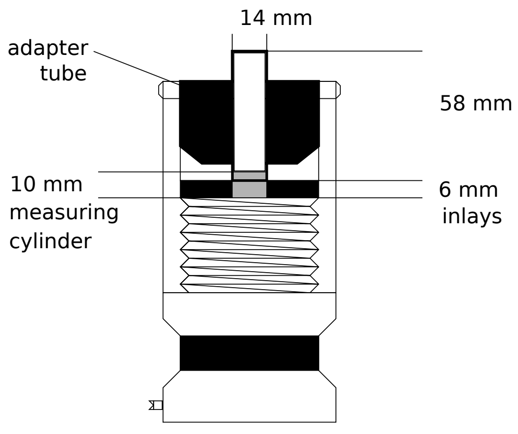

Figure 6: Cross section of the BIAS measuring head with new customized adapter tube, replacing the Eb-clarinet mouthpiece.

[3]Brass Instrument Analysis System

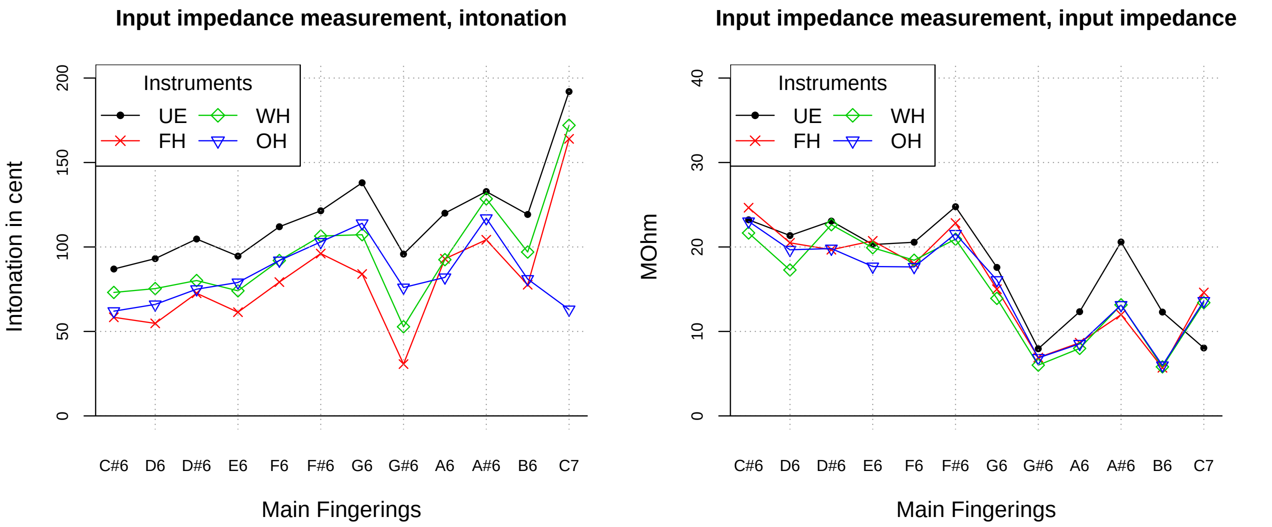

Figure 7: The intonation curves of the input impedance measurements (left) show two kinks at G#6 and B6. These tones are problem tones. The same can be seen at the input impedance curves (right).

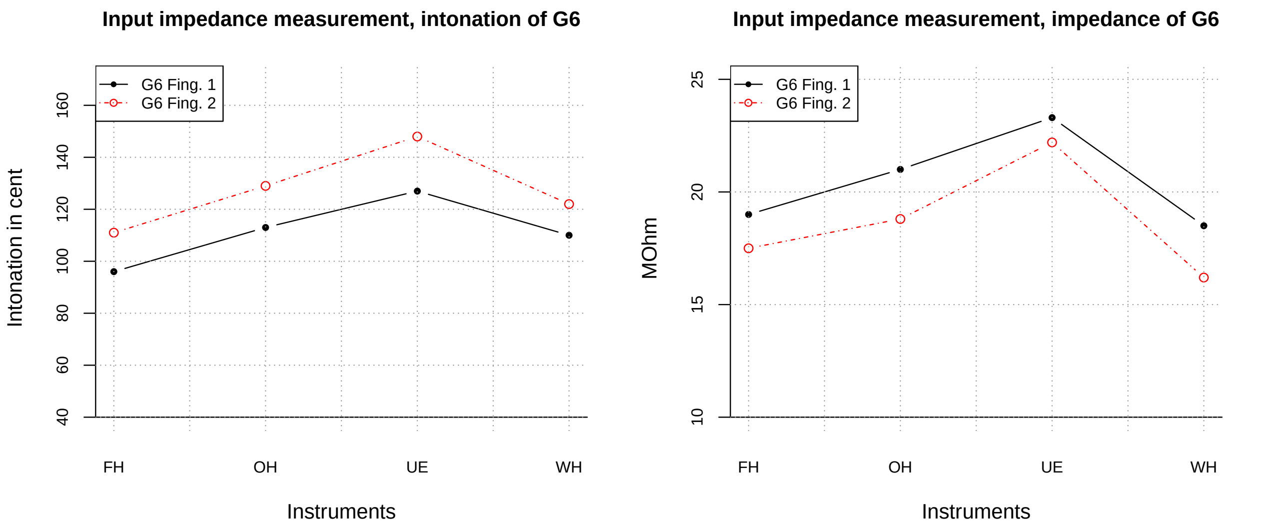

Figure 8: An alternative fingering (G6 Fing. 2, red) resulted in a sharper pitch, but with a lower input impedance (right), in comparison to the main fingering (G6 Fing. 1, black) on all Eb-clarinets.

3.3.2. Procedure

The 12 main fingerings (C#6–C7) and two alternative fingerings (G6Fing2, G#6Fing5) were measured separately on four Eb-clarinets (14 fingerings X 4 Eb-clarinets).
From these 56 input impedance curves the coordinates of the input impedance peaks (input impedance and frequency), which were close to the targeted frequency, were manually extracted with the curser in BIAS. Furthermore, the author counted the mode (Input impedance peak) of the extracted coordinates. The raw data (Fingerings, Frequency, Input impedance, Mode) was exported from a excel table into R-statistics. In R-statistics the pitch for each fingering was calculated to the equal tempered scale for further analysis.

3.3.3. Results

In the first analysis the 12 main fingerings were investigated. The analysis shows that the measured pitch is much sharper (>50 cent) than the expected pitch on all main fingerings (see figure 7, left). Normally, the measured pitch is close to the targeted pitch. The increasing intonation curves (see figure 7, left) show two kinks at G#6 and B6. The intonation of these both tones indicate possible problem tones. The same can be seen taking a look at the input impedances (see figure 7, right). On all instruments G#6 and higher tones resulted in a very low input impedance. This low input impedances could be a second indicator for problem tones.
In the second analysis the main fingerings of G6 and G#6 were compared with the alternative fingerings (G6 Fing. 2, G#6 Fing. 5). Figure 8 shows the input impedance measurement of the

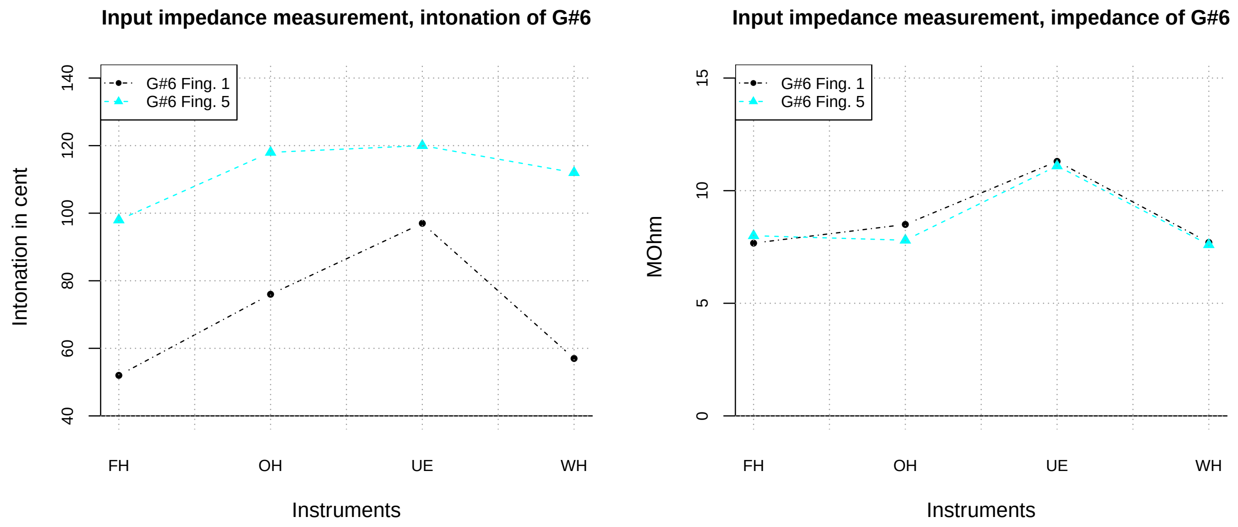

Figure 9: An alternative fingering (G#6Fing. 5, cyan) resulted in a sharper pitch and had nearly the same input impedance (right) in comparison to the main fingering (G#6 Fing. 1, back).

main fingering (G6 Fing. 1, black) and alternative fingering (G6 Fing. 2, red) for G6. The alternative fingering G6 Fing. 2 (red) resulted in a sharper pitch, but with a lower input impedance on all Eb-clairnets. The input impedance measurement confirms the influence of a sharper pitch in the audio recording. The same can be seen in figure 9 of the main fingering (G#6 Fing. 1, black) and alternative fingering (G#6 Fing. 5, cyan) for G#6. The alternative fingering G#6 Fing. 5 (cyan) resulted in a sharper pitch and had nearly the same input impedance on all Eb-clarinets.

In the third analysis the main fingerings were assigned to the respective modes. The analysis (see table 3) shows that the modes of the main fingerings, which were chromatically arranged, did not ascend with higher tones. The order of the modes changed from G#6 upwards.

Tone	**Mode**	**Frequency**	**Register**
E3–A#4	Mode 1	197.3–558.1 Hz	chalumeau
B4–C6	Mode 2	591.3–1253 Hz	clarion
C#6–E6	Mode 3	1327.5–1578.7 Hz	altissimo
F6–G6	Mode 4	1672.5–1877.4 Hz	”
G#6	Mode 3	1989 Hz	”
A6	Mode 5	2107.3 Hz	”
A#6/B6	Mode 7	2232.6–2365.3 Hz	”
C7	Mode 6	2506 Hz	”

Table 3: The altissimo register tones are played on the 3^{rd} mode or higher. The arrangement of the modes changes from G#6 upwards.

4. DISCUSSION

This study investigated the altissimo register on four Eb-clarinets in two different experiments.

In the first experiment the author recorded twelve main fingerings with up to 8 alternative fingerings on four Eb-clarinets in an anechoic chamber. The results showed that the pitch of the altissimo tones can be subdivided into 3 groups (see figure 2). In the first group (C#6–F#6) the pitch resulted in a correct intonation, in the second group (G6 and G#6) the tones were too flat and in the third group (A6–C7) tones were produced which were more than a halftone too flat. Alternative fingerings corrected the intonation in the second group (G6 and G#6), but no other fingerings helped to correct the pitch on higher tones than G#6.

In the second experiment the twelve main fingerings and two alternative fingerings were measured through input impedance measurements on four Eb-clarinets. The results of the main fingerings indicated two problem tones (G#6 and B6, see figure 7). The main fingering for G#6 showed a flat intonation and a low input impedance. The same was the case for the tone B6.

Two alternative fingerings (G6 Fing. 2 and G#6 Fing. 5) helped to correct the pitch offset in the audio recording. This can be confirmed by the input impedance measurements (see figures 8, 9). Additionally, the modes changed from G#6 upwards (see table 3). A comparison between the played intonation of the audio recordings (red) and the calculated intonation of the input impedance measurements (blue) shows that both intonation curves drift apart (see figure 11).

It is hypothesized that the reed characteristic (mass, stiffness) and the vocal tract configuration may be the reason for the problem tones of the second and third group of tones (G6–C7, see figure 11).

The resonance frequency [22, 23] of the reed (f),

$$f = 1/2\pi * \sqrt{(Stiffness/Mass)} \quad (1)$$

is proportional to the root of the stiffness (higher stiffness = higher resonance frequency) of the reed, vice versa to the mass. When the playing frequency is below f, the stiffness and the mass of the reed do not influence the playability [22, 23]. The higher the played notes, the more important becomes the mass and the stiffness of the reed. Some clarinetists use Bb-clarinet reeds on Eb-clarinets. They cut the reeds at the end to fit them to the shorter lay of the Eb-mouthpiece. The reed's natural frequency is in the range of 2000–4000 Hz [18, 24], which overlaps with the tones G#6 (1989 Hz)–C7 (2506 Hz) on Eb-clarinets (Table 4).

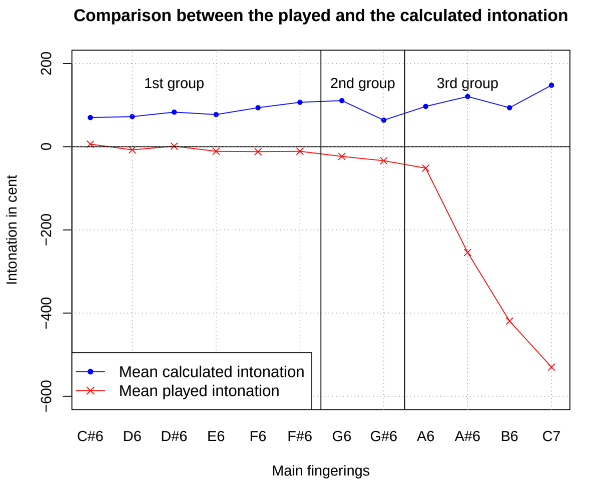

Figure 10: The intonation curves of the audio recordings (red) and the input impedance measurements (blue) drift apart for the main fingerings.

Playing range	E3		G6	C7
Eb-clarinet	**197.3 Hz**	–	**1877.4 Hz**	(2506 Hz)
Bb-clarinet	**147.8 Hz**	–		**1877.4 Hz**

Table 4: Eb-clarinets and Bb-clarinets have the same frequency limit. The note G6 on the Eb-clarinet corresponds to a C7 on the Bb-clarinet. The frequency of the note C7 on the Eb-clarinet has a frequency of 2506 Hz, which is close to the reed's natural frequency.

It is recommended to use harder reeds in the altissimo register [3, 25, 26], which can be explained by their characteristic to have a high resonance frequency f.
Chen et al. [27] have shown the influence of the vocal tract resonances on the pitch in the altissimo register. This is caused by the overlapping between the vocal tract resonances and the bore resonances. Under the condition of low impedance peaks inside the instrument, the impedance of the players vocal tract has to be considered. Additionally, in the altissimo register the reed's natural frequency is close to the playing frequencies on Eb-clarinets. It was observed that the end of the playing range of the instruments was A6. Harder reeds, which have higher resonance frequencies, might help to improve the intonation of altissimo tones and increase the playing range.
In summary, it is assumed that from a certain point on, when the input impedance peaks decrease, other factors (e.g.: reed characteristics, embouchure settings) have a strong influence on the resulting pitch. To better understand the behavior of the Eb-clarinets in the altissimo register, measurements including vocal tract resonance, reed resonance, blowing pressure, and lip pressure measurements are foreseen. From such enhanced measurements the significance of these factors can be determined.

5. AUTHOR CONTRIBUTIONS

Conceived and designed the experiments: MG. Performed the experiments: MG AH. Input impedance measurements: MG. Analysis of the recordings: AH MG. Wrote the paper: MG

6. ACKNOWLEDGMENTS

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7. APPENDIX

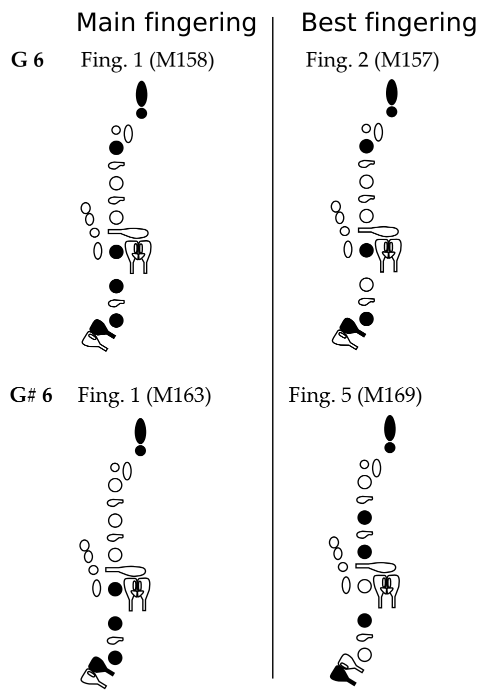

Figure 11: Alternative fingerings (best fingerings) helped to correct the pitch for the tones G6 and G#6. For the tone G6, a slightly change (opening the middle finger of the right hand) of the main fingering sharpened the pitch. For the tone G#6, a completely different fingering compared to the main fingering resulted in a sharper pitch.

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