Intonation on trumpets

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Abstract: The purpose of this study was to determine the intonation properties of trumpets and to compare empirical data of played trumpets with a.) theoretical tuning systems like equally tempered, Pythagorean tuning or just intonation and b.) with the "objective intonation" which has been calculated by means of input impedance measurements. Another aim of this study was to evaluate the size of inter- and intra-individual variability in performances. Results show that there are great differences amongst players even playing the same reference instrument. The arithmetic mean over all trials correlates best with the equally tempered system. In the middle register, the calculated "objective intonation" matched played intonation even better.

INTRODUCTION

Tone generation on trumpets is influenced by many parameters. Variation of the played intonation are caused by either the instrument, the player, or both. The intonation of the instrument is determined by the mechanical dimensions of the instrument and the mouthpiece. The position of resonance frequencies, the so called "objective intonation", can be calculated using the input impedance method. Statistical data taken from 35 trumpets will be presented and compared with the pitch of notes blown by the player (so called "subjective intonation"). The "subjective intonation" can vary for many reasons. It can be caused by the physiological condition of the lips of a player or the increasing participation of higher harmonics in a crescendo. The desired timbre of the sound can cause variations as well. These variations can be more than 50 cent with the same instrument as shown in a previous study (BERTSCH 1997). The main objective of this study was to find out if players follow the tuning of the instrument or if rather they are trying to perform one of the musical scale models as equally tempered, Pythagorean tuning and just intonation.

METHODS

MEASUREMENT OF THE "OBJECTIVE" INTONATION OF TRUMPETS : 36 trumpets in B-flat have been measured using the "Brass Instrument Analysing System" BIAS, a Hard and Software system developed at the *Institut für Wiener Klangstil* (IWK). [Widholm, 1995]. BIAS measures the input impedance of brass instruments. Frequencies of impedance peaks are detected and set into relationship with the equally tempered scale. The reference frequency for A4 is calculated in a way that the mean deviation of the impedance peaks 2-6 and 8 (which correspond to the natural tones Bb3, F4, Bb4, D5, F5, Bb5) is a minimum. Then the departure of all notes from their ideal location is calculated taking all valve combinations of the instrument as well as the refrence frequency - usually about 440 Hz …445 Hz, - into account. This calculation method (the so called „without weighting“ method; WGT=0) assumes that the excitation signal is a sinusoidal signal. In reality the excitation signal of a real player will instead have a sound spectrum containing many harmonics with different amplitudes. Therefore not only the impedance peak at one frequency (the fundamental of the particular note) has to be taken into consideration, but all multiple frequencies of the fundamental of the virtually played note. The contribution of each partial of the excitation spectrum to the „over all“ impedance of a particular note has to be weighted according to the relative amplitude of the excitation spectral line. BIAS allows different weightings to simulate different dynamic conditions resp. sound spectra of the excitation signal. Usually a “standard weighting” (WGT=2) is used, where the magnitude of the impedance of higher partials is weighted by $\frac{1}{\sqrt{x}}$ (x being the index of the harmonic). This relationship has been found in preliminary studies to correspond well with mezzoforte dynamic. The present study is another approach to find an appropriate formula.

Analysis of performed intonation of players: trumpet players have been recorded in the anechoic chamber of our institute playing several tasks in two sessions. The first trial was played on their own instrument, while in the second trial, a reference trumpet in Bb (Romeo ADACI, Referenz 2001) together with a reference mouthpiece (BRESLMAIR G1) had to be used. Only the rim of the mouthpiece could be chosen by the player. The detailed set up was already described at ISMA 97 [Bertsch, 1997]

The subjects were 35 musicians having 18.5 years of experience in average. 20 of them were highly trained professionals and members in established Vienna orchestras. The other 15 were advanced trumpet students or amateurs with a wide range of experiences. 24 were playing a trumpet with rotary valves in the first trial, 11 one with Perinét valves. The reference trumpet has Perinét valves, too.

The musicians were asked to play the given music as if they would perform on stage. No special instructions were given to concentrate on the intonation in order to receive realistic samples. Two scales in F major have been analysed. Note that this corresponds to G major when the notation is for a trumpet in Bb (fig. 1). Task F3-4 starts at F3 in the lower register of the instrument and ends in the middle register one octave above. Task F4-5 covers the next octave from F4 to the beginning of the high register of the trumpet at F5. One note, the F4 (written as g4) is played and analysed twice.

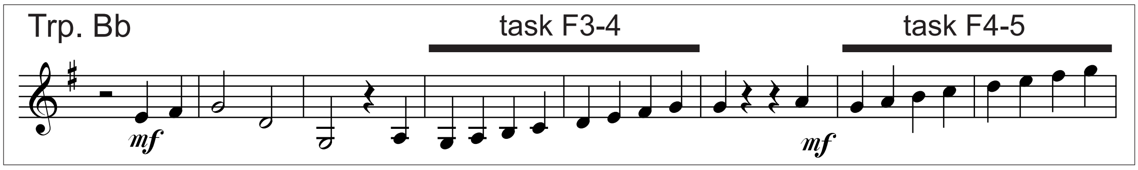


FIGURE 1 Musical context of task F3-4 and F4-5 played on trumpets in B-flat.

Duration and articulation was not defined more precisely. The dynamic should be *mezzoforte*. The growing tension of the ascending scales and the influence of the different dynamic range of the instrument in lower and upper registers caused all players to perform a crescendo. In average, the F5 was played 13dB louder than F3. i.e. an increase of 6 dB per octave. The inter individual variability was remarkably more than 14 dB in each register which demonstrates a different interpretation of mezzoforte. Correlation between intonation and dynamic was part of the previous study.

Each single note played on a brass instrument varies in pitch, even without any vibrato. Most notes in a ascending scale also ascend from their beginning to their end. To receive only one fundamental frequency (f0) for each blown note, digital signal analysis has been applied. Fundamental frequencies have been detected (fs: 44,1 resp. 48kHz; window lengths: 2048 Samples) when at least four partials were fitting into a harmonic grid. Additionally the RMS was plotted. As relevant frequency (in this study referred to as the oberseved mean frequency) the frequency at the moment with maximum amplitude (RMS) has been considered. (Only in some cases a more constantly played frequency was chosen.) The upper part of figure 2 shows the f_0 played by one player as the note C5. Each data point indicates the fundamental frequency as a result of a harmonic grid analysis. The first and last 50ms of each tone, - one FFT window length -have been omitted. Absolute frequencies have been transformed into relative intervals corresponding to an individual tuning. (A4 between 438 Hz and 445 Hz.) For the determination of A4, the minimum departure of all natural tones (no valve engaged) have been taken into consideration. The arithmetic mean, 443 Hz (SD: 2 Hz), illustrates the actual custom to tune to a higher frequency than the current international standard tuning frequency for western music, 440 Hz. Additionally the minimum and maximum frequencies have been tracked to determine the variation of one note.

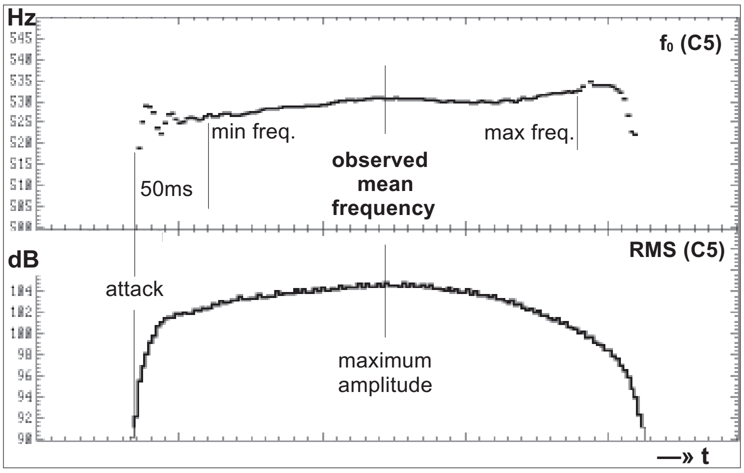


Figure 2. Detection of the played fundamental frequency.

RESULTS

MEASURED INTONATION: BIAS measurements of 35 trumpets in B-flat have been made and the average departure of the calculated intonation from the equally tempered system is shown in Fig.3. In the lower register there is a great difference between a graph without weighting (WGT=0) - where notes are very flat,

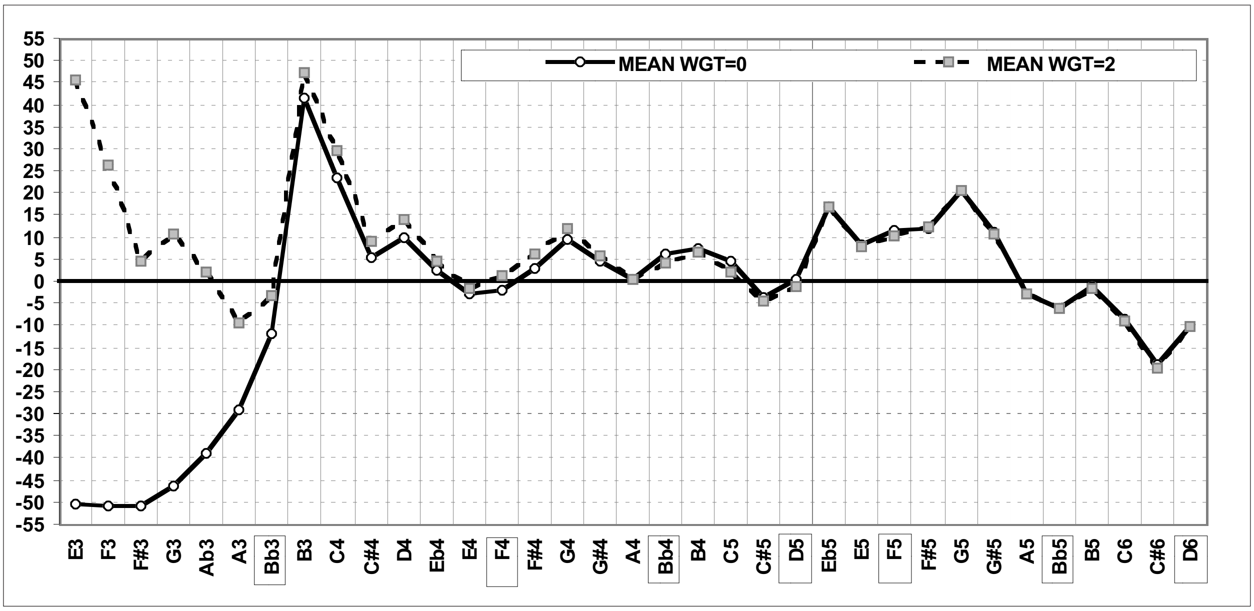


Figure 3. Departure from equally tempered scale in cent (arithmetic mean of all BIAS measurements)

and one with standard weighting (WGT=2) - where notes in the 3rd octave are rather sharp. In the middle and high register, variations between weightings are very small. For most values (except 3rd octave of WGT=0) the analysis shows that if more than one valve is engaged t he effective length of the additional tube is too short. The resulting tone is sharp. In fig. 4, the values (for WGT=2) for each valve combination which are used in standard fingering are shown separately. This well known fact can on almost all instruments be corrected manually using a trigger. Especially for B3 and C4 the use of a trigger is always recommended.

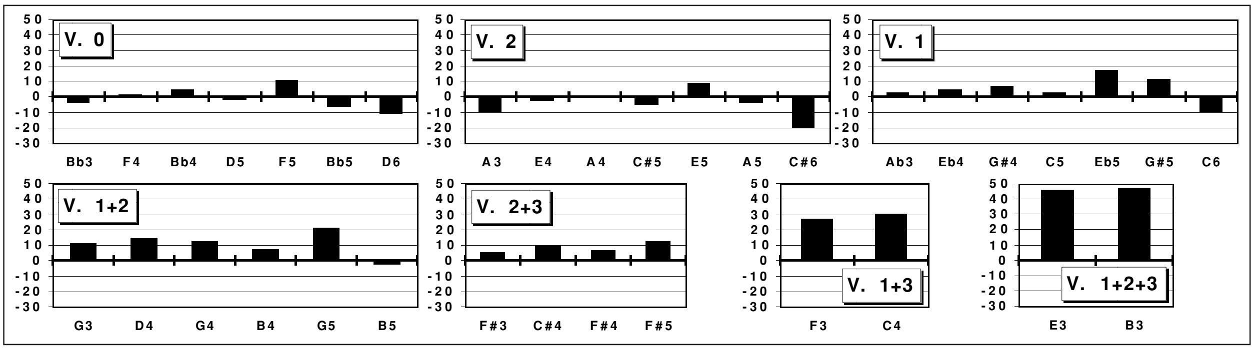


Figure 4. Intonation error in cent for each valve combination (BIAS WGT=2)

Besides this characteristic, which is connected to the valve combination, it is remarkable that all notes blown using valve 1 are sharp (except C6). Furthermore, notes blown at the 6th resonance frequency tend to be very sharp (Eb5: +17 cent; F5: +10 cent)

<u>Played intonation:</u> Recordings of 35 trumpet players have been analysed regarding of their intonation performance within two F major scales. In Fig. 5 a huge inter-individual variation of the observed mean frequencies can be seen. The overall distance between maximum and minimum is about 30-40 cent, and in the lowest register even more. Astonishing is the variety of played intonation on the reference trumpet.

Compared to the equally tempered system, the arithmetic mean of all played intonations fluctuates between sharp and flat. (See table 1) Remarkable is the note A3, which is more than 16 cent flat and the notes C4, G4 and F5 which are played more than 10 cent higher than the equally tempered scale. The associated

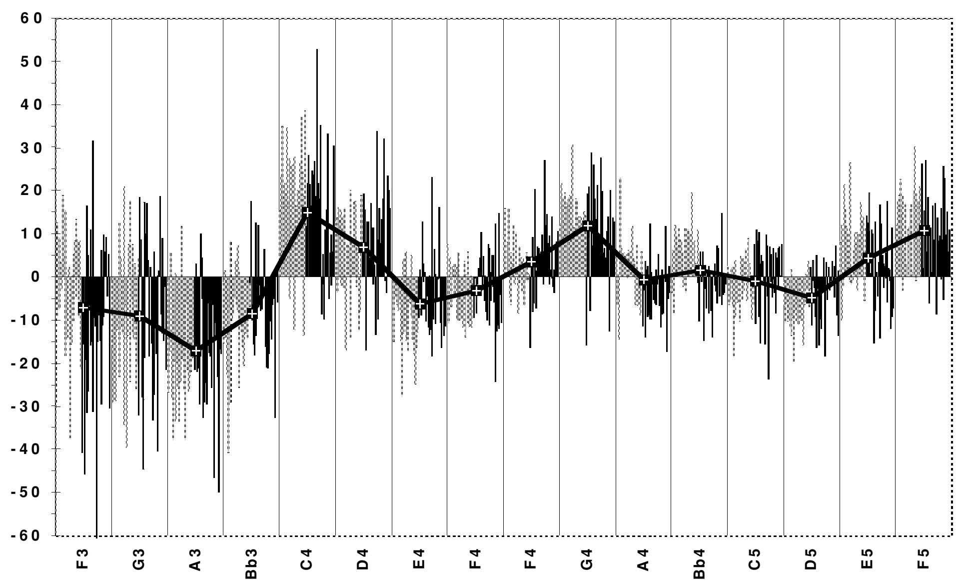


Figure 5. The actually played intonation of all trumpeters (departure from the equally tempered scale in cent). The black curve indicates the arithmetic mean over all sessions. The individual values are shown as black narrow bars for values played with their own individual instrument and grey bars for the session played on the reference trumpet.

standard deviation (SD) for tones in the lower register is about 15 cent, in the middle and upper register approxamately 7 cent. The SD for trials on the reference trumpet (R) is only slightly higher (1 cent) than for the trials played with individual instruments (I).

Intonation differences between I and R exist for some particular tones, which are caused by the type of the trumpet. On instruments with Perinét valves (like R), the A4 and Bb4 are about 6 cent sharper, C5 and D5 are about 7 cent more flat as on instruments with rotary valves (like most of I).

The fact that the second F4 is in average 7 cent higher than the first shows the importance of musical context. In this case the second F4 is played right after the G4, which is very sharp.

If the intonation of both tasks is compared, (see fig. 6) almost no common trend concerning interval relationship can be found. This makes an underlying general "theoretical system" unlikely. Remarkable is that both keynote octaves are larger than 1200 cent. Moreover, 7 of 9 occurring octaves are stretched. In order to compare the played intonation with theoretical tuning systems like equally tempered, Pythagorean and just intonation, the departures have been calculated and plotted in Fig. 7. In general, trumpet performance most closely conforms with equally tempered intonation. Departures from each model are much greater than differential threshold (about 3 cent).

Table 1. arithmetic mean, in cent of departure from the equally tempered intonation over both trials (I+R) together with standard deviation and for each trial seperatly.

	I+R MEAN	I+R SD	R MEAN	I MEAN
F3	-7,1	17,3	-2,9	-11,7
G3	-9,2	15,8	-10,6	-8,3
A3	-16,9	12,4	-18,4	-16,0
Bb3	-8,4	10,4	-10,2	-7,2
C4	15,0	13,0	16,0	13,5
D4	6,9	10,5	5,6	8,4
E4	-6,1	8,8	-8,2	-3,7
F4	-3,1	7,2	-3,6	-2,1
F4	3,7	7,2	3,0	4,5
G4	12,0	8,3	13,5	10,4
A4	-0,6	7,0	2,2	-3,1
Bb4	1,6	6,8	4,9	-1,8
C5	-0,8	7,1	-2,2	0,5
D5	-4,7	6,3	-6,3	-3,0
E5	4,5	8,6	6,6	2,6
F5	10,9	8,0	12,2	9,7

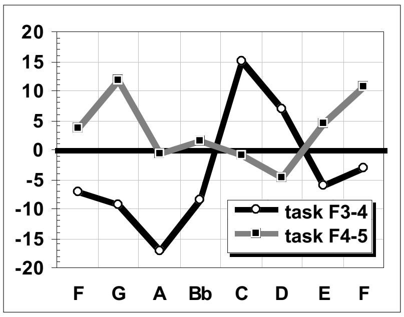


Figure 6. upper / lower octave (Δ ET)

Additionally, the played intonation of certain groups of players selected from all players has been statistically analysed. As a result, little significant difference was found between professional and student players, between younger and older players, or between male and female musicians. Diversity was found to exist only on notes with extreme deviation. For example professionals played the C4 and G4 five cent less sharp than amateurs and students. Especially the C4 was played very sharp by players with less experience.

The examination of the played tones reveals further a great difference between minimum and maximum for each note within the scale. 26 cent in average among all players for the trials on their own instrument, and 28 cent for trials with the reference trumpet. In the lower register the average variation of some notes was even more than 50 cent. Of course, during the ascending scale, most slurs have been upwards.

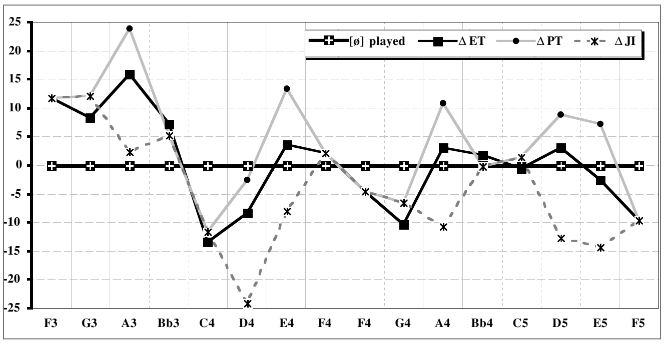


Figure 7. Departures from theoretical intonations in cent. Ordinate corresponds to played intonation on indiv. instruments

MEASURED VERSUS PLAYED INTONATION:

A comparison of the arithmetic mean of the variety of subjective intonations of an instrument as played by a player and the “objetive intonation” as measured using BIAS shows a good matching in the middle register. In Fig. 8 a disagreement can be only found in the lower register, where weighting influences the result to a great extent. The standard weighted intonation measurement approaches the played intonation more closely which can be taken as an indication that an improvement of the weighting algorithm could be a good way to further improve correlation between played and measured intonation.

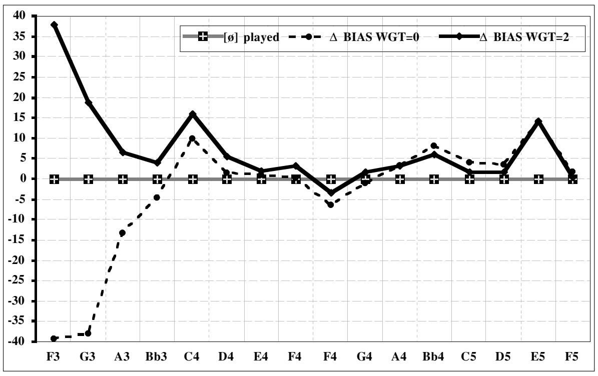
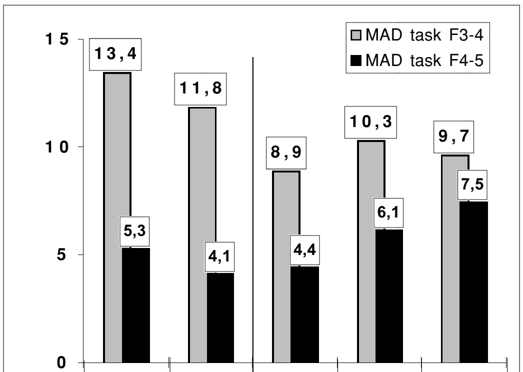


Figure 8. Departures of BIAS measurements from the played intonation in cent. Ordinate corresponds to played intonation on indiv. instruments.



	Δ BIAS WGT=0	Δ BIAS WGT=2	Δ ET	Δ PT	Δ JI
F 3-4	**13,44**	**11,84**	**8,87**	**10,33**	**9,65**
SD	*16,13*	*12,21*	*4,73*	*7,11*	*7,10*
F4-5	**5,31**	**4,11**	**4,45**	**6,15**	**7,47**
SD	*4,24*	*4,44*	*3,62*	*3,86*	*5,18*

Table 2. Mean absolute difference (MAD) in cent between observed played intonation on players own instruments and BIAS measurements without (WGT=0) and with standard weighting (WGT=2). Further MAD and theoretical musical systems: equal tuning (ET), Pythagorean tuning (PT) and just intonation (JI). **Figure 9.** shows MAD for each task seperately.

SUMMARY

The main results of the present study are summarized in table 2 in which the arithmetic mean of the MAD values and the associated standard deviations are tabulated. Visual inspection of Figure 9 shows: a.) that trumpet performance in regard to theroretical tunings most closely conforms to equally tempered intonation and b.) that the standard weighted “objective intonation” model matches played intonation especially well in middle register. Therefore, it can be concluded that trumpeters follow the tuning asserted by the instrument rather than trying to match a theoretical scale.

For the player, a perfect „objective intonation“ that matches his „intended intonation“ could free him to concentrate on other aspects. Since technical tools are able to optimise the „objective intonation“ of brass instruments (Anglmayer and Kausel 1998), the question arises which ideal intonation a musician expects from his instrument. Usually only extreme departures are considered as a real problem, because much energy is needed for correction.

ACKNOWLEDGMENTS

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