STEMCO

The sound level and frequency spectrum of a Crystal Soundboard™ Piano in comparison to Pianos with conventional spruce soundboards.

issue: 23rd June 2017

STEMCO, Crystal Sound Board™

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Note to the reader:

"As the subject Atjoli upright piano is also produced under two other brand names: i.e.: **Goodway** and **Julius Kreutzbach** which are, model for model, identical in design, construction, quality, tonal characteristics and touch, the author wishes make the reader aware of these synonymous instruments"

1 INTRODUCTION

Crystal Board

As long as the piano has been in existence relentless efforts have been made to improve and achieve, amongst other features, specific desired *tonal characteristics* and to a lesser extent, *tuning stability.*
Variations in use of (quality-)materials, and general primary constructive processes during manufacture determine the final tone and playing characteristics of the instrument.
Besides humidity, -temperature variations and induced vibrations during use or transportation of the instrument, **tuning stability** is an aspect directly related to the use of particular materials in the sound board and bridges.

The Crystal Sound Board is invented and developed by Kees de Baat (piano tuner, -technician and inventor of the Crystal Sound Board™) from the STEMCO company in Monnickendam in the Netherlands, with these aspects firmly in mind. In his unique and remarkable quest to improve tone and tuning stability he successfully introduced the radically new concept of using a soundboard solely constructed of **toughened glass.** Besides achieving a breakthrough in tonal qualities and far greater tuning stability, It provides a far more homogenous tone with less unwanted vibrations, a longer and brighter, more beautiful sustain combined with a more modest output volume.
Ardea Acoustics have compiled this comprehensive independent report to measure, analyze and evaluate the sound of a piano equipped with a Crystal Sound Board™ in comparison to traditional spruce sound board pianos.

This report

This report compares the sound of a modified Atjoli piano equipped with a Crystal Sound Board with an identical Atjoli piano with a traditional spruce sound board. Additionally, 24 other traditional upright pianos have been acoustically analyzed and evaluated to establish an accurate reference. Twelve of these reference pianos are privately owned and used (period 1913-2002), the other twelve recently build upright pianos (period 2004-2008) placed in a typical showroom setting.
The comparison processes are conducted in controlled environments using highly sensitive and accurate recording equipment under strict industry standards to assure uncompromised data results.
The recordings were carried out by Hans Troost and the results evaluated and compiled by Wim Soede.
To supplement the evaluated sound measurements and give it a more subjective evaluation Hans Troost, piano tuner and musician, has included some of his thoughts and comments throughout this report. He understands and is able to eloquently describe, in a comprehensive yet simple manner, the beauty of *tone, sustain* and rich *color* that Crystal Sound Board pianos possesses.

2 PERFORMANCE OF SOUND ANALYSIS

Meter — For all sound level measurements Sound Level Meter type NA-28, type 1 is used. Its certificate of calibration with number 167799 was issued on 29th Oct. 2008

Positioning — To accurately assess the entire 'noise-exposition' from a musician's perspective the meter is positioned on a stand at ear-level, i.e. around 1.30 meters from floor level.

Livingroom — The sound analyses were conducted on 26th august 2009 in a domestic living room in a dwelling in Maarn, the Netherlands. Two identical Atjoli upright pianos were analysed side by side for sound level and tonal evaluation. One had an original spruce sound board and the other a Crystal Sound Board. Shortly after, between 27th aug-5th sept 2009, twelve privately owned upright pianos were analyzed for sound level and tone. These pianos belong to Troost Muziek's clientele for regular tuning and maintenance. The data extracted from these pianos, built between 1913-2002, thus averaging 50+ years of age, provides a solid reference for an unbiased comparison in tonal and volume outputs between spruce-, and CSB™ pianos.

Showroom — Additionally, sound analyses have been performed on twelve more 'newer' upright pianos in a large piano showroom. These instruments were built between 2004 and 2008.

Acoustics — All Audio recordings and analyses have been performed with the sound level meter's microphone positioned at the pianist's ears, so at relatively short distance from the piano. One would be tempted to assume that because of this short measuring distance the acoustic effects in the room would not be significant. That is proved to be incorrect for reasons explained in appendix 2. In an average living room, initial reflections off the rear facing wall and ceiling contribute to increases of the peak levels measured after the first 10-20 milliseconds. Furthermore, in comparatively smaller living rooms the level of reverb will be relatively higher. In a larger showroom these effects will be less.

Atjoli — To compare both Atjoli pianos (spruce vs CSB™)every note has been struck manually without the use of sustain or damper pedals during the recording sessions. Also, a short musical piece is played and recorded, again without the use of sustain or damper pedals.

A1-A6 — All 26 pianos (two Atjoli's and 24 other) have undergone a measurement using a falling weight for notes A1, A2, A3, A4 *, A5 and A6 (A1, A, a, a', a'', a''' respectively, see appendix 1) followed by another musical piece played and recorded in WAV-format for further analysis.

*A4 equals a' (= 440 hz)

Analysis

All captured recordings have been evaluated afterwards using the aforementioned sound level meter. An sound level decay analysis break-down specified to one second (1s)* intervals for each recording provides the sound level decay graph as depicted in the example below. For each fraction of every one second (1s) interval the average sound level and peak sound level sample rates are set at device setting ‘A’ which equates to a sample rate interval of 10 ms.

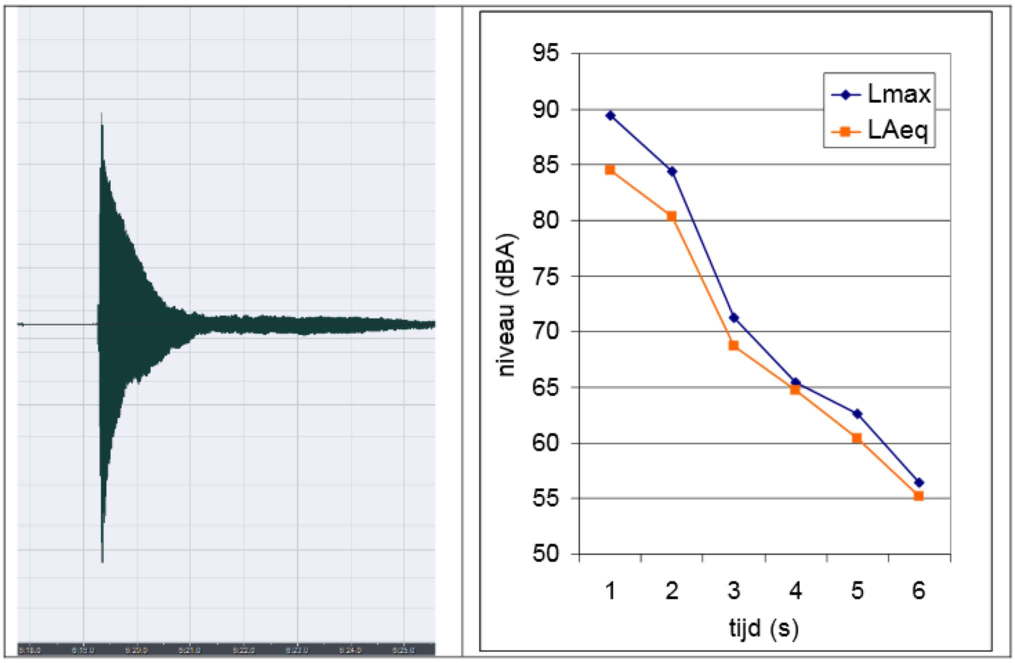


Figure 1: Example of analysis original keystroke sound level decay in seconds (Lmax and LAeq)

*A rounding off to the nearest second (s) is regarded as a good rate for keystrokes during modest piano play with the metronome set to 60 clicks/min.

3 RESULTS OF SOUND ANALYSIS AND EVALUATION

3.1 Atjoli piano with Crystal Sound Board™ or spruce sound board

The recordings and analyses have been carried out on two identical Atjoli upright pianos, Both of type A1, except for their sound boards; one spruce and one CSB™type.

3.3.1 Sound levels A0-C8 per octave

For both Atjoli pianos sound level measurements have been carried out for each key from A0 to B7 by striking them separately. Fig. 2 depicts a summary of the *average*- and *peak levels* for the defined octaves (incl. A0 and B0). Adjacent to these values the total values across the entire key range is shown from A0 to B7. This totaled value is the *average* sound level value of all 88 keys.

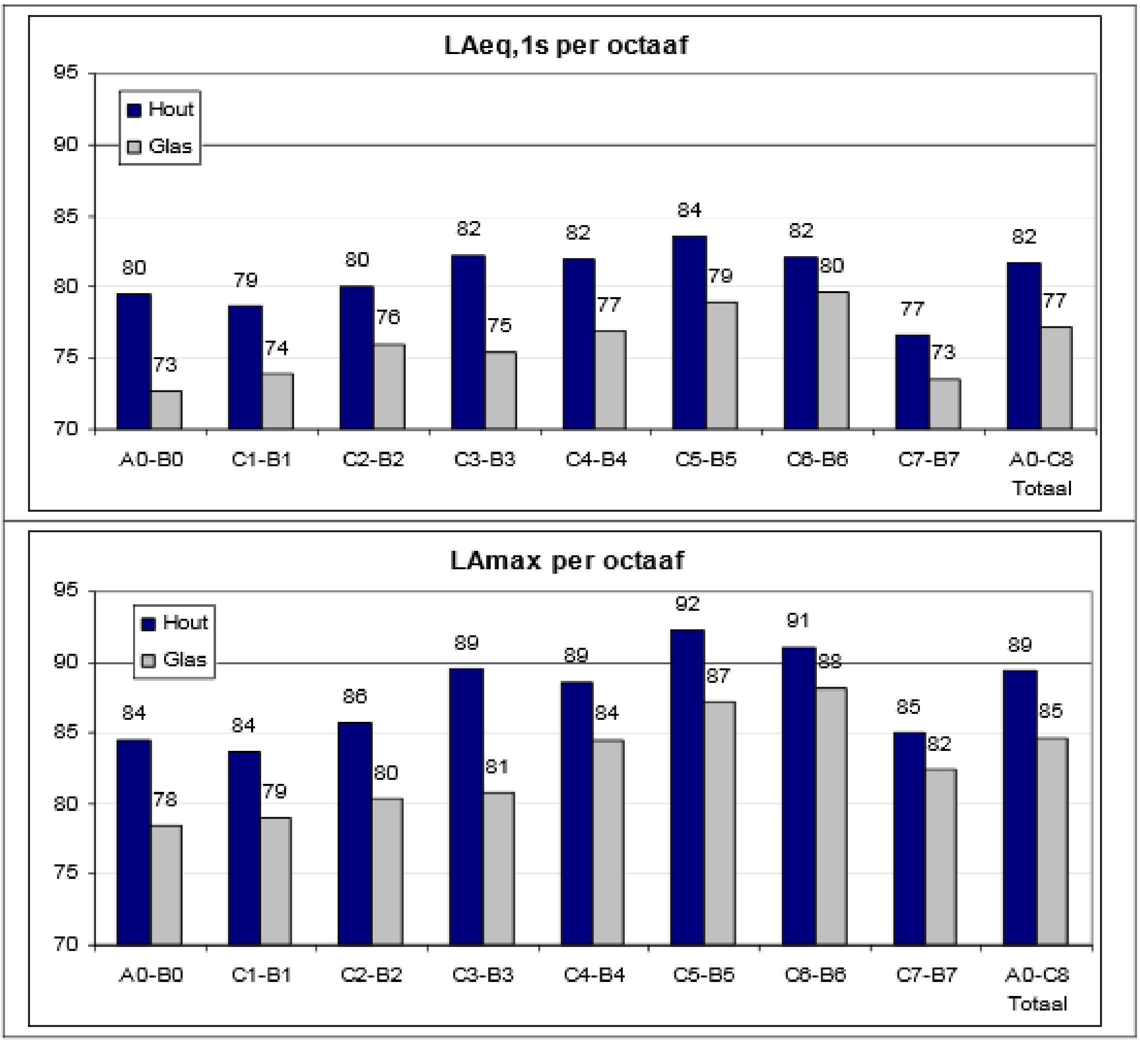


Fig 2: Summary of analysis sound level measurements per octave

3.1.2 Spectral analysis of tone

Regarding the Crystal Sound Board tone, various evaluators have subjectively described the tone qualities to be of a clearer type and possesses a richer palette of audible overtones (see also chapter 4). This motivated the client and researcher to include a frequency analysis for octaves C2-C6 in an attempt to provide a visual objective and scientifically sound fundament for these aural observations. To ensure the comparison between the two pianos is accurate, both sound board recording sets have been normalized to a value of 80 dB(A). Fig 3 depicts the results for keys C2-C6. From this graph it is evident that the measured values for said notes between the two pianos does not differ significantly. (only 2.2 dB) Considering the spread in measuring results this difference is considered negligible.

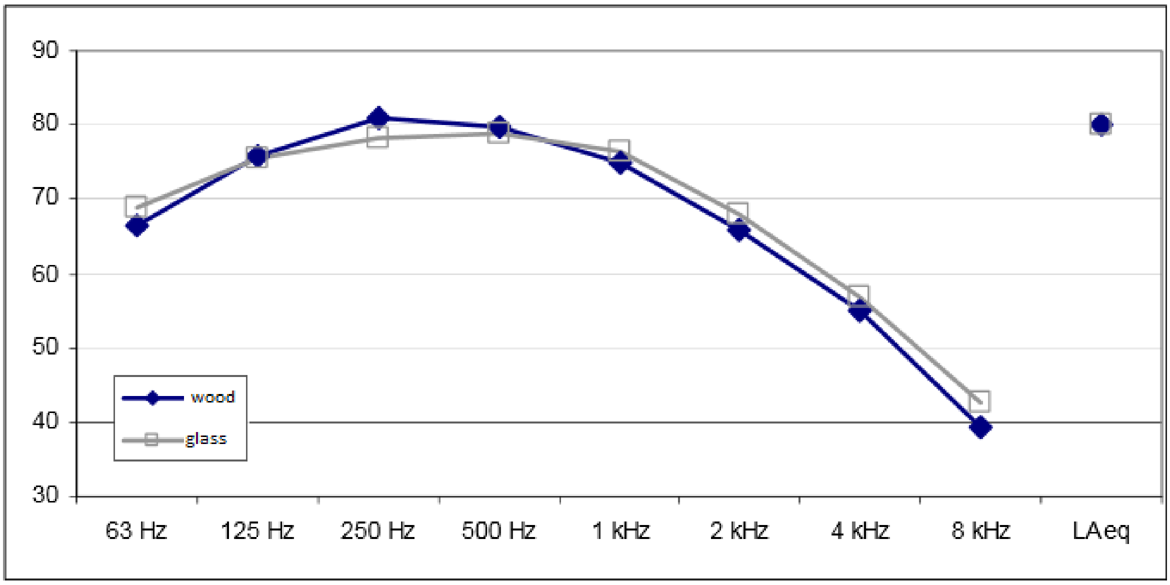


Fig 3: Frequency distribution keys C2-C6 normalized to 80 dB(A) based on 1s measuring intervals

The previous spectral analysis is based on measuring values obtained within 1s after keystroke and represents the average value for both the fundamental frequencies *and* their overtones. To investigate possible deviations between fundamental frequencies and overtones over the decay period a further evaluation for two groups of notes C3-B3 and C5-B5 has been conducted as shown in fig 4 and 5. The solid line represents the sound level of the fundamental frequency.

C3-B3 Referring to fig. 4 we can extract that for both sound board types the combined energy produced by the overtones is greater than the energy produced by the fundamental frequencies. The value difference between fundamental frequency and corresponding overtones for a spruce sound board vs CSB™ is 6.7 dB and 4.3 dB respectively. This implies that the spruce sound board exerts more overtones compared to the CBS™. However, after 2-3 seconds the situation reverts. The spruce sound board's fundamental frequency decays much faster (4 dB/s). The relative difference between fundamental frequency sound energy level and that of its overtones increases. The absolute sound energy decays much faster as well which equates to a shorter sustain compared to CSB™

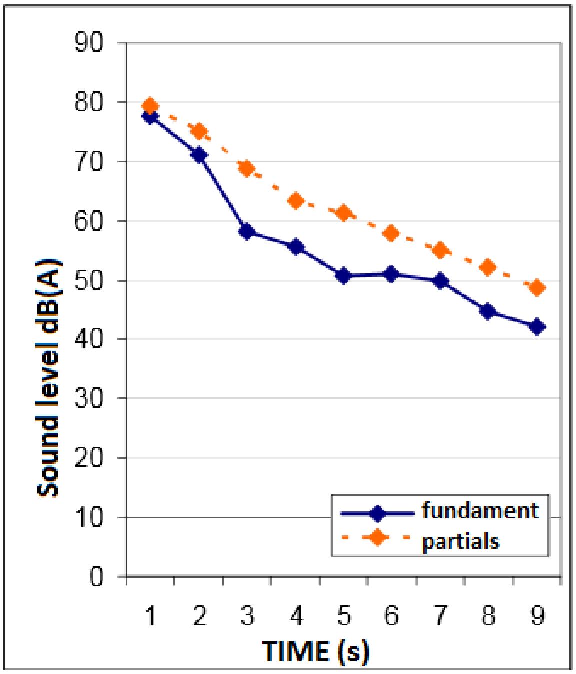
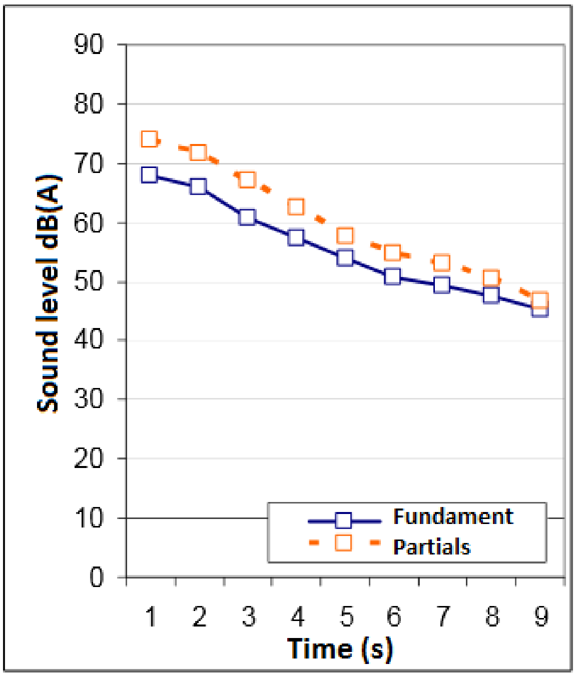
Spruce sound board	**Crystal Sound Board CSB™**
C3-B3	**C3-B3**
 	
Decay Fundament: 4.0 dB/s Decay Partials: 3.4 dB/s Diff fundament/partials: -6.7 dB	Decay Fundament: 2.5 dB/s Decay Partials: 3.0 dB/s Diff fundament/partials: -4.3 dB

Fig 4 Sound levels and decay over time for fundamental frequency and corresponding partial frequencies for spruce (left) and CSB™ (right) soundboards. Average data for 7 notes (C3-B3).

Spruce sound board	**Crystal Sound Board CSB™**

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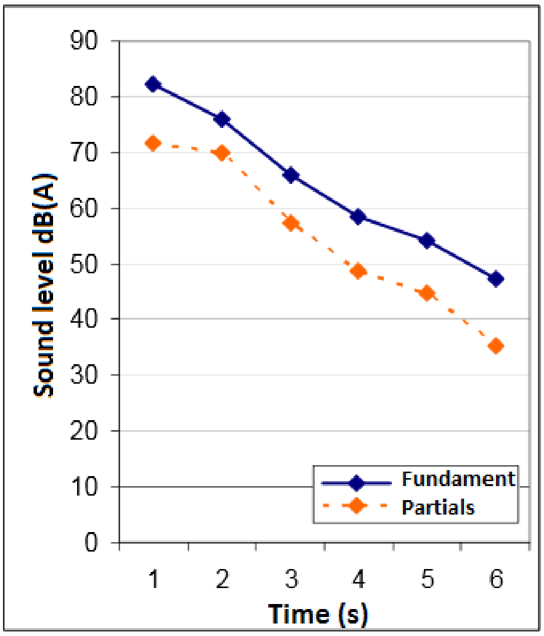
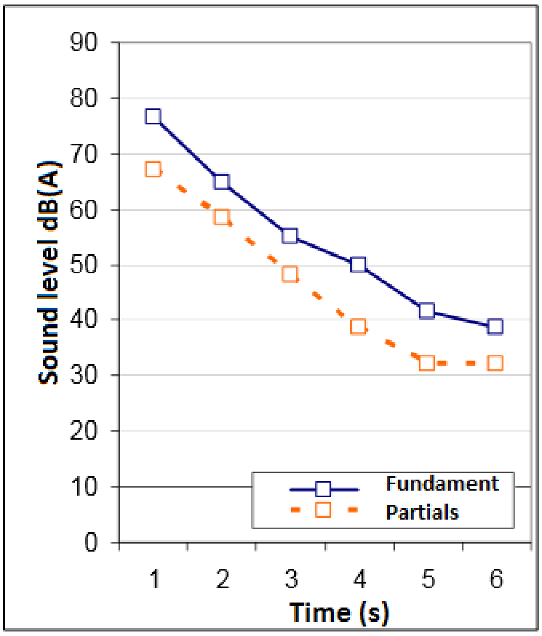
C3-B3



Decay Fundament: 5.8 dB/s
Decay Partials: 6.0 dB/s
Diff fundament/partials: 9.4 dB

C3-B3



Decay Fundament: 6.3 dB/s
Decay Partials: 5.8 dB/s
Diff fundament/partials: 7.6dB

Fig 5 Sound levels and decay over time for fundamental frequency and corresponding partial frequencies for spruce (left) and CSB™ (right) soundboards. Average data for 7 notes (C5-B5).

Concerning the Crystal Sound Board™ the difference between the fundamental- and partial frequencies is initially small but remains more constant. The decay occurs at a slower rate (2.5-3 dB/S). It results in the fundamental and partial frequencies becoming equal in sound level after about 2 seconds after the keystroke.

C5-B5

for tonal range C5-B5 the relationship between Fundamental- and partial frequencies becomes *inverted*. Referring to fig 5 it becomes evident that for both sound board types the energy for all combined partial frequencies is *less* than the energy level of the fundamental frequency. The mentioned difference for a spruce sound board is 9.4 dB and 8.3 for a CSB™.The Crystal Sound Board is therefore relatively richer in partial overtones by a modest 0.9 dB, which is not significant. The decay rate for both types are almost similar at 6dB/s.

Based on this analysis it is conclusive to state that the CSB™ in comparison to spruce sound boards possesses a longer sustain or lower decay rate for notes C3-B3. After 2 seconds after keystroke the sound level becomes equal of that of a spruce sound board piano with relatively more energy in the partial overtones or frequencies. At higher notes (C5-B5) these differences are less dramatic.

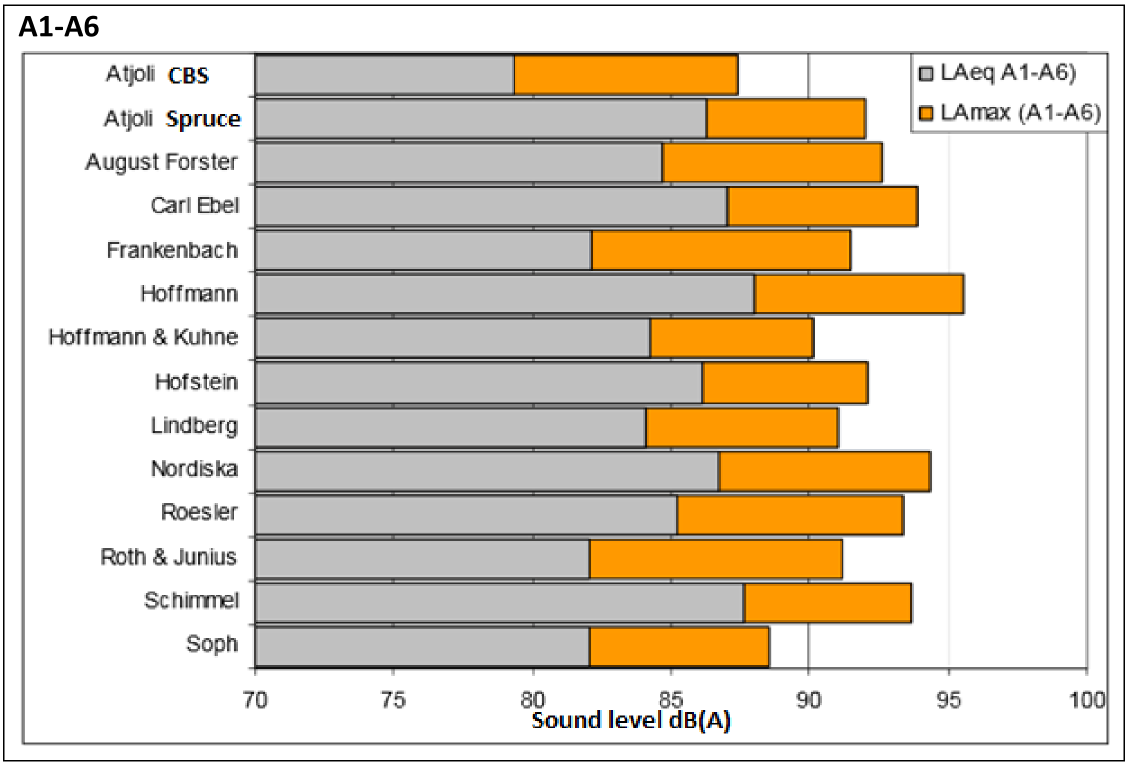
3.2 Comparison Atjoli pianos vs twelve other upright pianos (living room)

3.2.1 Comparison sound levels

Notes A1-A6

To facilitate this research properly a fixed weight is used from a pre-determined height to depress each key with an exact equal impulse. The noise created by the weight impacting on the key surface is not relevant due to its sound level being 15 dB less than the peak sound level of the string after keystroke.

Figure 6 provides a summary of the sound levels directly after keystroke (average over 1 s and peak level within that 1st second). From this summary it is evident that, with the exception of the Atjoli with CBS™, the average sound level of ALL pianos is above 80 dB(A). The average sound level for the Atjoli CBS™ is 79 dB(A). The Frankbach, Roth & Junius and the Soph are 3 dB(A) louder with an average sound level of 82 dB(A). The loudest pianos are the Carl Ebel, Hoffmann and the Schimmel with 87-88 dB(A). The Hoffmann peaks the highest at 96 dB(A).



PLAY

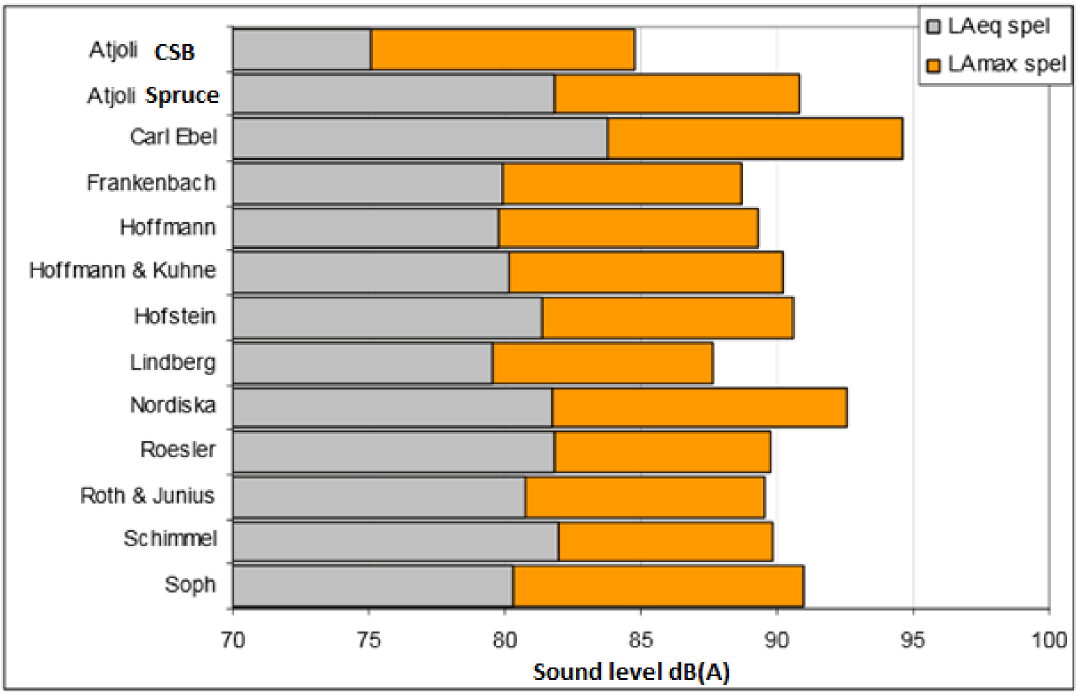


Fig 6 Average and peak sound levels of keystrokes A1-A6 (upper graph) and during play (bottom graph) for 14 pianos

Play

Additionally to the standardized keystrokes A1-A6, Hans Troost played a short original composition on every instrument, consisting of a series of harmonic chords and progressions without the use of any damper or sustain pedals. It is chosen deliberately to reproduce mezzo-forte level of play.

The average peak sound levels are summarized in figure 7. From this graph we can extract that the Atjoli CSB™ performs around 5 dB(A) softer in both *average* and *peak level*s compared to all other assessed pianos. This difference matches the previously analyzed results for the keystrokes A1-A6 very closely.

3.2.2 Comparison of frequency spectrum

The same recordings as summarized in paragraph 3.2.1 have been assessed for their specific frequency spectrum. Figure 7 provides a summary of the frequency spectra of both Atjoli pianos in comparison to the other twelve assessed pianos. From this analysis it is evident that the Atjoli CSB™ sounds anywhere between 5 and 11 dB softer at frequencies up to 400 Hz. During play is the difference less at around 5-6 dB for all frequencies between 250 and 4000 Hz.

A1-A6

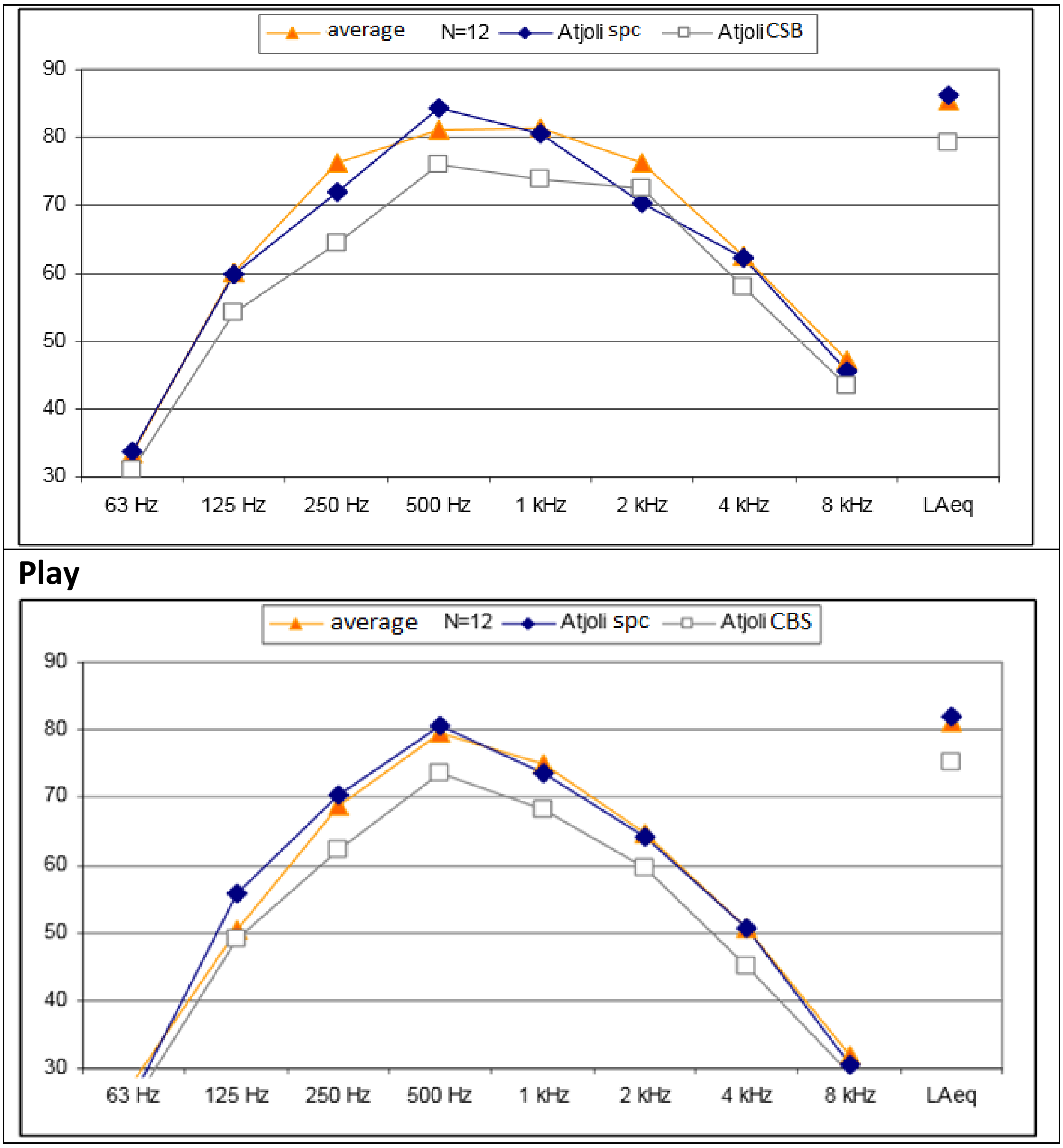


Fig 7 Analysis frequency spectrum average levels A1-A6 (upper)and during play (lower)

3.3 Comparison Atjoli pianos vs twelve other upright pianos (show room)

3.3.1 Comparison Sound levels

Notes A1-A6

To facilitate this research properly in the show room, a fixed weight is used from a pre-determined height to depress each key with an exact equal impulse. The noise created by the weight impacting on the key surface is not relevant due to its sound level being 15 dB less than the peak sound level of the string after keystroke.

Figure 8 provides a summary of the sound levels in the show room directly after keystroke (average over 1 s and peak level within that 1st second). During the recordings, for both Atjoli pianos, an acoustic correction for the reflections was applied during analysis of 4 dB. See also appendix 2.

A1-A6 From this summary we can extract that the averaging peak sound levels of the Yamaha UYS3S, Yamaha 1SG, Petrof 125M1 and Schimmel K132 are the lowest. The Atjoli CSB™ is in this summary similar to this group.

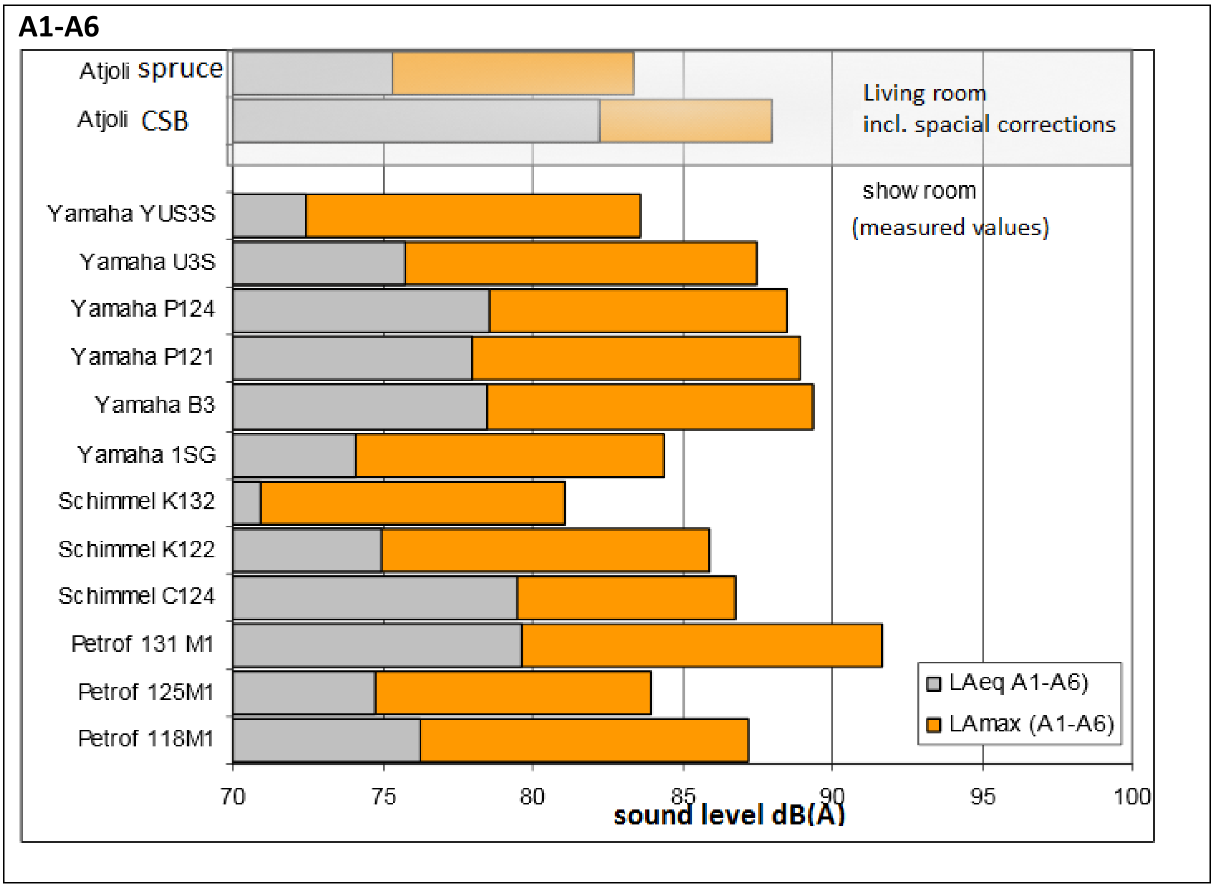


Figure 8 Average and peak sound levels of keystrokes A1-A6 for 12 pianos in showroom. The measurement values of the atjoli's have been conducted at a different location and have been corrected for the acoustical differences between a living room and a show room.

Play

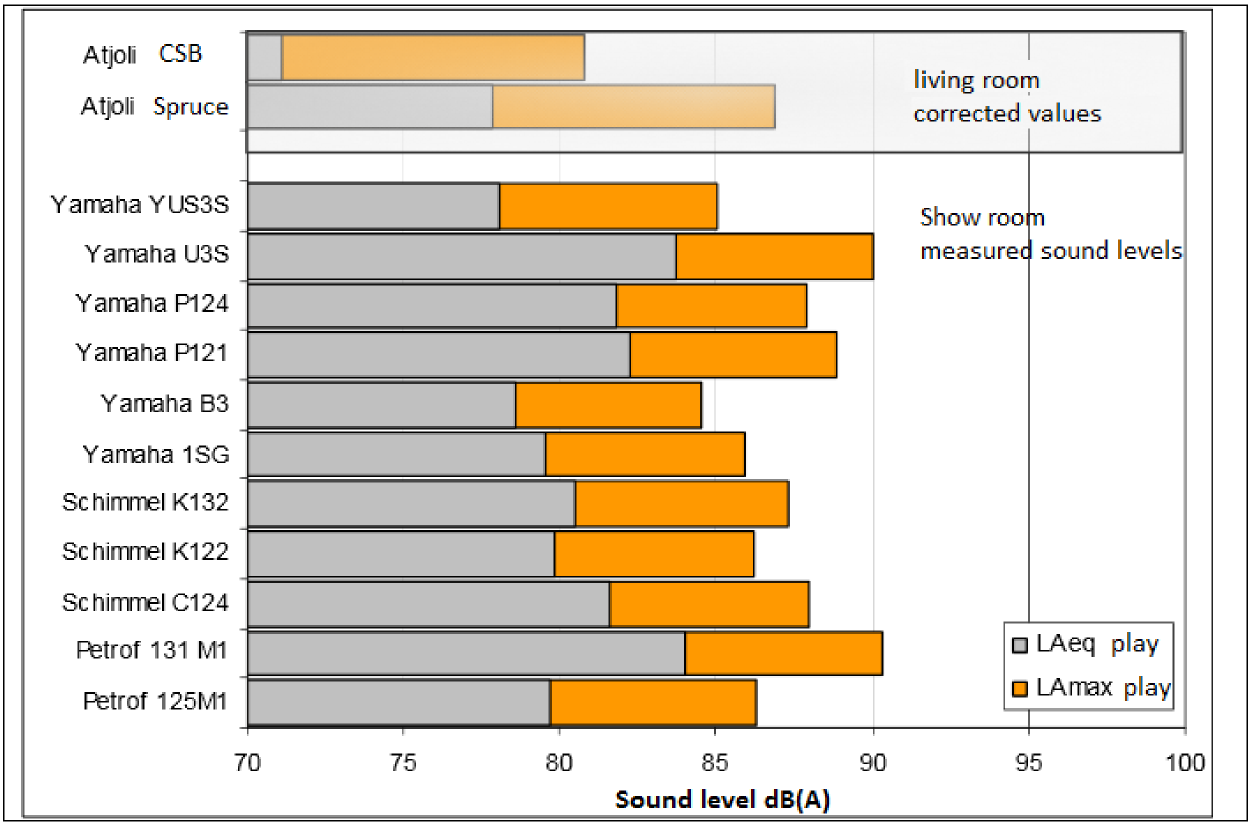


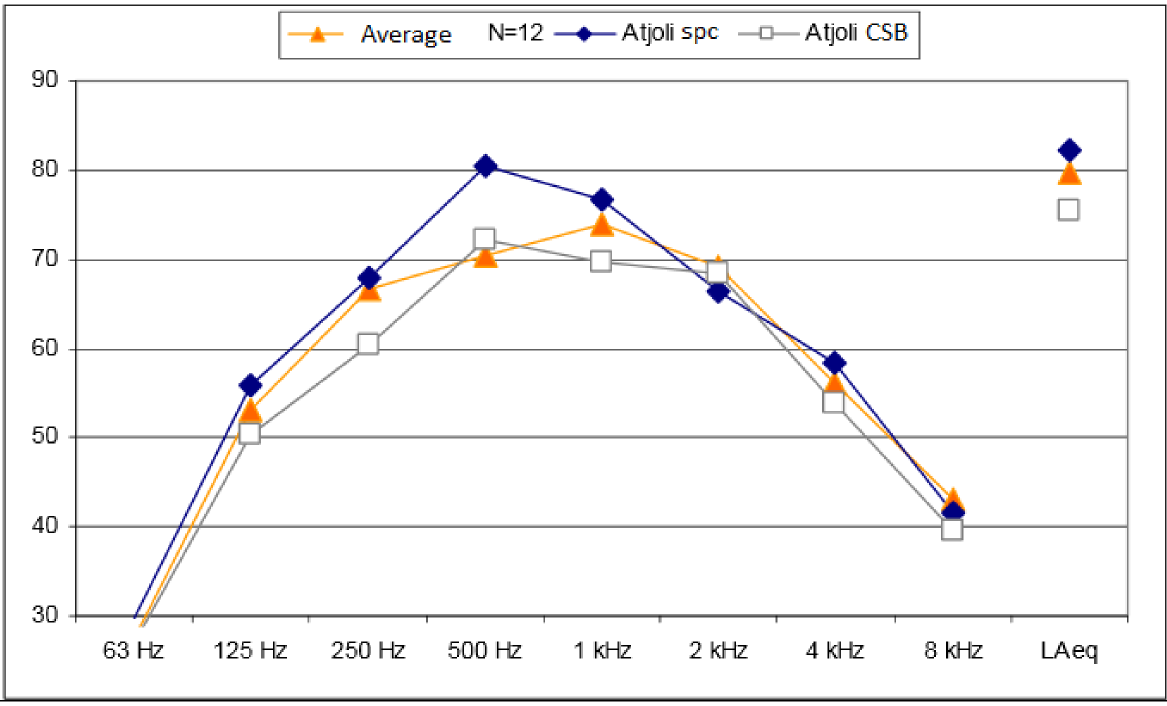
Figure 9 Average and peak sound levels for play in show room. The measured values for the Atjoli's have been acquired elsewhere and have been corrected to compensate the acoustical differences between a living room and a show room.

Additionally to the standardized keystrokes A1-A6, Hans Troost played a short original composition on every instrument, consisting of a series of harmonic chords and progressions without the use of any damper or sustain pedals. It is chosen deliberately to reproduce mezzo-forte level of play. The average peak sound levels are summarized in figure 9. From this graph we can extract that the Atjoli CSB™ performs around 5 dB(A) softer in both *average* and *peak level*s compared to all other assessed pianos.

3.3.2 Comparison of frequency spectrum

The same recordings as summarized in paragraph 3.2.1 have been assessed for their specific frequency spectrum. Figure 10 provides a summary of the frequency spectra of both Atjoli pianos in comparison to the other assessed pianos. From this analysis for A1-A6 it is evident that the Atjoli CSB™ sounds slightly softer. The Atjoli Spruce sound board paino has a higher sound level in the mid-section 500-1000 Hz in comparison to the other pianos. During play it is remarkable that the shape of the *average* spectrum graph of the twelve pianos in the show room is identical to those both Atjoli upright pianos. The Atjoli CSB™ possesses the lowest sound levels for all frequencies.

A1-A6 Measuring results spectral analysis show room pianos vs Atjoli's incl. acoustical correction



Play Pianos show room vs Atjoli's including acoustical correction

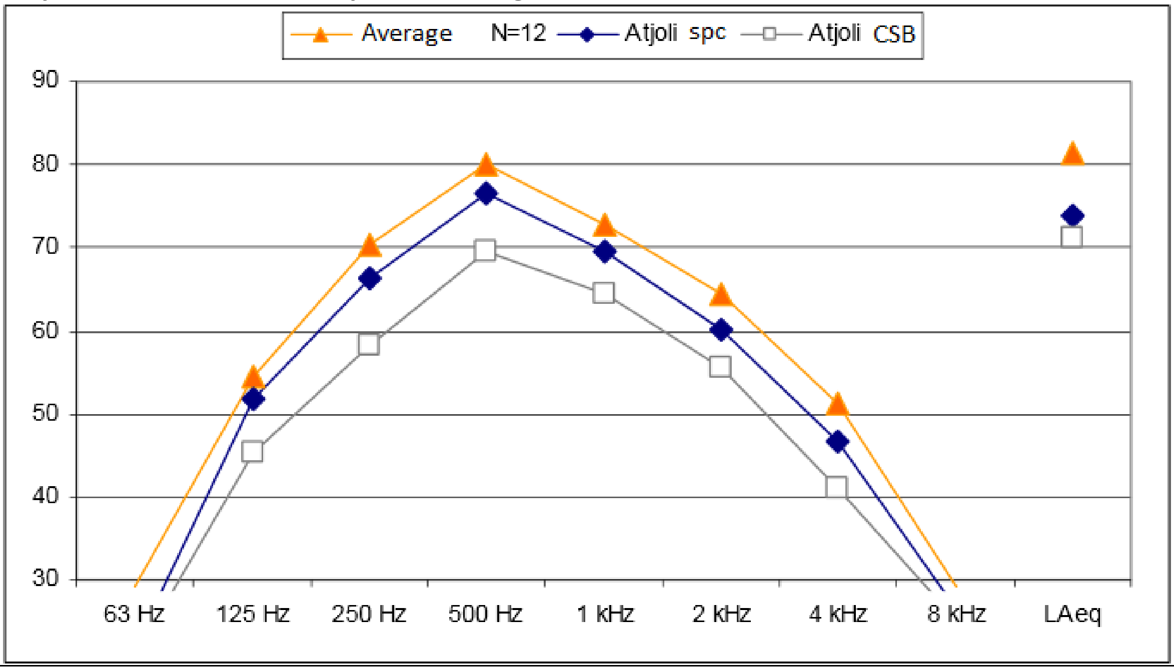


Fig 10 Analysis of frequency spectrum average sound levels A1-A6 (upper graph) and during play (lower graph).

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4. AURAL EVALUATIONS ATJOLI

Piano tuning During tuning all known tonal features/characteristics* are presented, just like every piano tuner /technician is familiar with in any regular piano with a spruce sound board. When listening closely with a critical technical inclination, these features appear more serene and balanced, comparatively to those characteristics found on instruments of superior quality and/or grander size. (for uprights 1.25 meters or taller, and for grand pianos from 1.80 meters in length.

Tone Listening with a profound musical ear, the Atjoli CSB™ has an open, brighter and richer tone, with far more sustain. From an inharmonic perspective, the tone appears rounder and slightly less inharmonic. Despite a more modest initial and overall sound level it will carry far within its space through more balanced partial frequency-richness. During ensemble settings, the Atjoli CSB™ will be heard very decently. This in contrary to many modern, predominantly smaller pianos, which often produces a compressed tone that sounds dull or even blunt to the ears. I.e. loud nearby and unclear at distance.

Loudness Unfortunately many of us interpret 'louder' as 'better' and many piano manufacturers are well aware of this unjustified assumption and will make 'loudness' an overrated yet presumed 'important' feature of their instruments. This has resulted in the fact that pretty much all modern (grand-) pianos have become so loud over the past one hundred years, that a daily exposure of over just a few hours can inflict permanent hearing impairment to a professional musician or driven amateur. The Atjoli CSB sounds less loud and sounds less penetrant. This enables a musician to perform longer sessions without the risk of damaging his or her hearing. Less loudness also reduces (aural-)stress.

Musically The unique combination of less loudness, greater dynamics across the tonal range and a richer, brighter sound makes the Atjoli CSB™ an alluring and inspiring instrument. In particular in the bass and tenor range this is noticeably apparent. This is where the Atjoli CSB™ truly sounds like a grand piano, and the added advantage that the bass will not mask the mid-section or treble, not even when playing with the sustain pedal depressed. This is mainly achieved by the Atjoli CSB's™ sound board being made in two defined sections. The particularly defined tone allows for complex harmonies with accompanying instruments in tight arrangements. This instrument has a broad musical horizon and is a source of inspiration for the advanced pianist.

*Tonal features/characteristics like : inharmonicity, false beats, over-resonance and variations in tonal coloring across the key range and in particular in the transition between bass, mid-section and treble.

5 CONCLUSION

Analysis

Based on analysis of the performed sound level measurement it is evident that:

- From an analysis of the sound level in the first second after keystroke for all keys ranging from A0-C8 the sound level for the Altoli CSB™ of the total tonal range is 5 dB lower than that of the spruce sound board equivalent Atjoli. For maximum sound levels measured, this difference is 6 dB.
- The frequency spectrum for both piano's is identical within the measuring tolerance.
- Based on analysis of keys C3-B3, the Atjoli CSB™ has a much longer sustain, or slower decay of sound levels compared to the Atjoli spruce sound board piano, which causes the partial overtones to be heard more dominantly after 2 seconds after keystroke. For key range C5-B5 is the volume level ratio between fundamental and corresponding partial frequencies virtually identical as well as the decay times.
- Comparing the two Atjoli's with 12 classic pianos in various living room settings it is apparent that the Atjoli CSB™ sounds an average of 5 dB(A) softer. Playing in Mezzo-forte the Atjoli CSB™ has an average sound level of 78 dB(A) in comparison to the other assessed pianos, including the Atjoli spruce sound board, which exert a sound level of 81 dB(A)on average.
- From analysis of 12 newer pianos it is evident that the average and peak sound levels of a Yamaha UYS3S, Yamaha 1SG, Petrof 125M1 and Schimmel K132 appear the lowest in sound level measurement results. The Atjoli CSB™ is comparable to this group when evaluating its sound levels. At Mezzo-forte play the Atjoli CSB™ sounds around 5 dB(A) softer.

Subjectively

The sound of the Atjoli CSB™ is comparable to that of finer quality upright- and grand pianos. The open, broader and richer tone with extra dynamics and sustain provides a highly defined tonal range which allows for an extra musical dimension. The only hurdle some of us need to overcome is our custom to traditional piano sound which is more than often defined by (excessive-)*volume* rather than many other beautiful aspects a tone can possess. This will require a shift in appreciation towards richer and more beautiful piano sound at the expense of a lesser sound level.

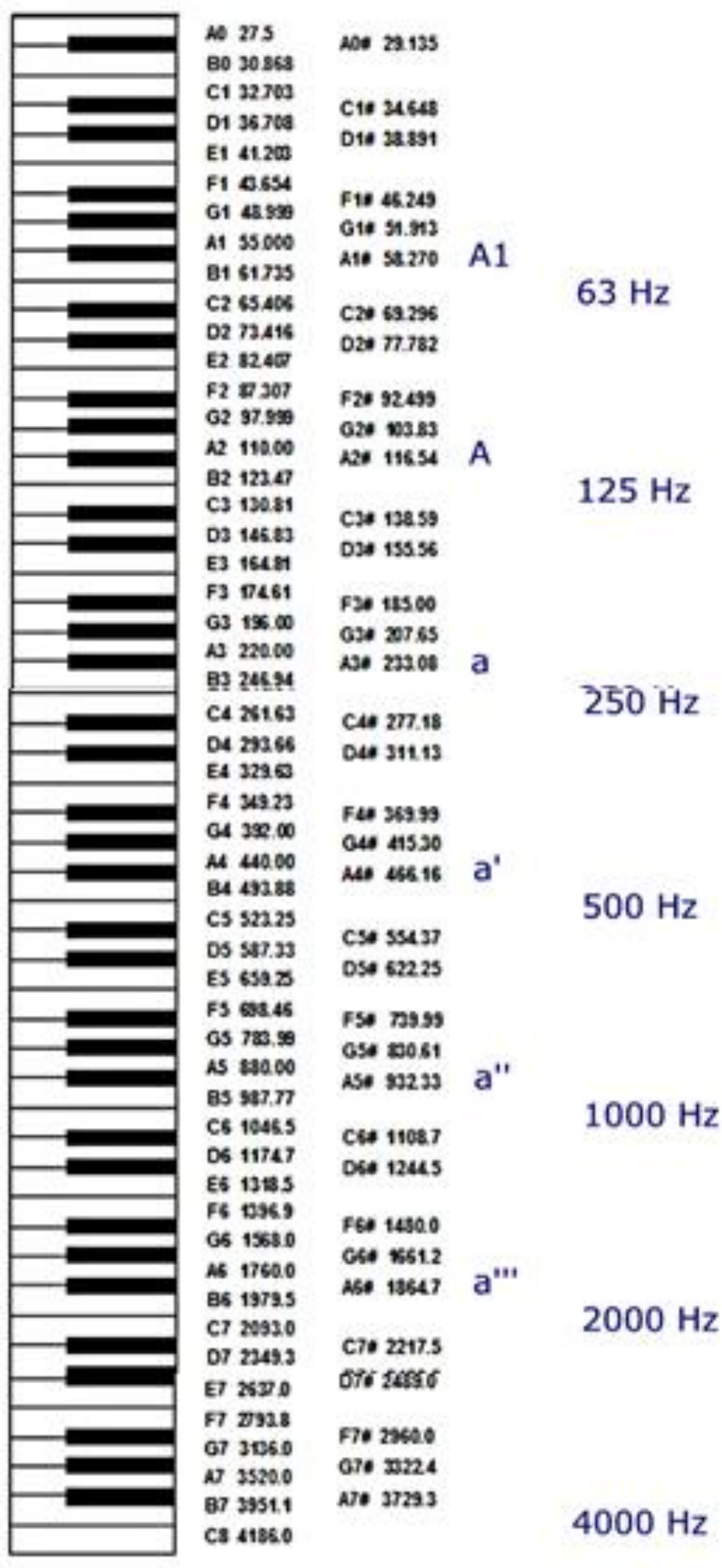
Conclusion

To summarize the totaling conclusions we have established that the Atjoli CSB™ produced sound levels during normal play between 5-6 dB(A) less than traditional spruce sound board pianos from a comparable size. This effect is most strongly evident in relatively small spaces like a living room or studio.

From the objective spectral analysis the Atjoli CSB™ has a remarkable even frequency spectrum. The subjective experience that the sound of this instrument is broader and richer in overtones is most probably the result of the longer sustained notes in the lower register. Most probably, the aural component of a reduced fundamental frequency sound level at keystroke ensures a lesser masking effect of overtones in the middle ear.

Based on all analysis performed the Atjoli CSB™ can be an excellent choice in preventing hearing damage or impediment.

Appendix 1: Overview of piano notes with corresponding frequencies



Appendix 2: Acoustic effects in various spaces

Outside

When a source of sound is positioned outside the sound can travel freely in all directions. The sound energy decreases exponentially with distance from the source. Logarithmically that equates to a reduction of 6 dB per doubling of the distance. E.g.: at 1 m distance of a source the sound is 69 dB, at 2 m distance 63 dB and at 4 m distance 57 dB and at 8 m distance 51 dB.

Closed space

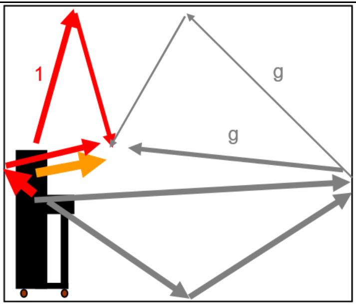
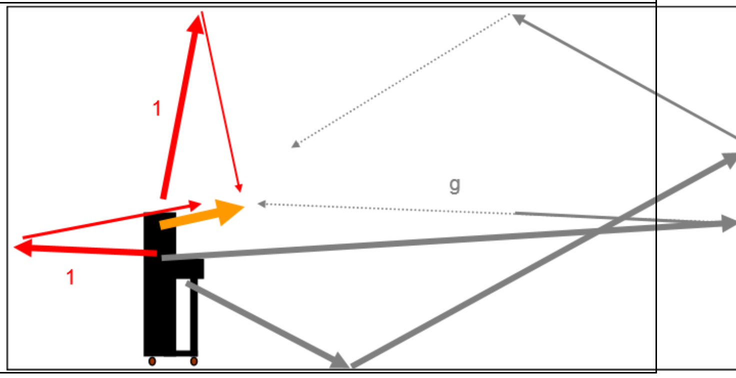
In an enclosed space the sound will reflect off the walls, ceiling and floor. Besides the direct sound of the source, the reverb palette will consist of all reflections. Depending on the decay time of the reflections and the reflection time, the first component will be added to the direct sound (integration-effect before 100-200 ms) and the second component will be heard as a reverb or echo. (reflection after 100-200 ms).

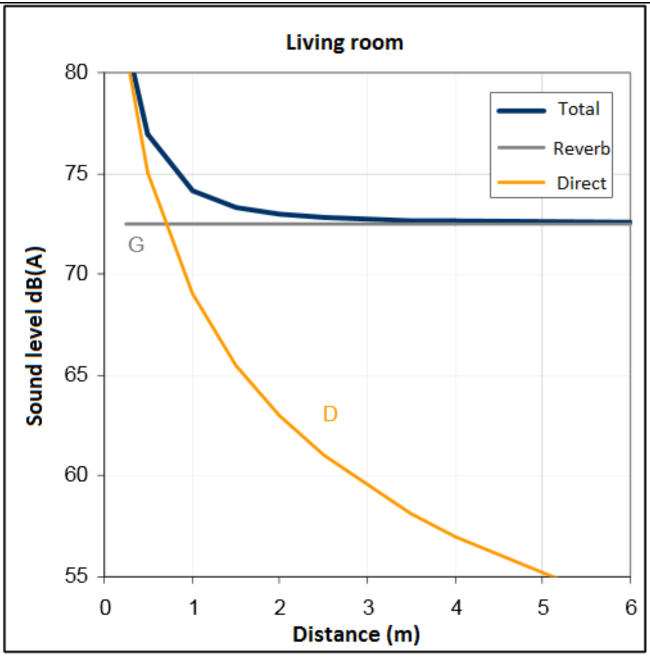
Living room

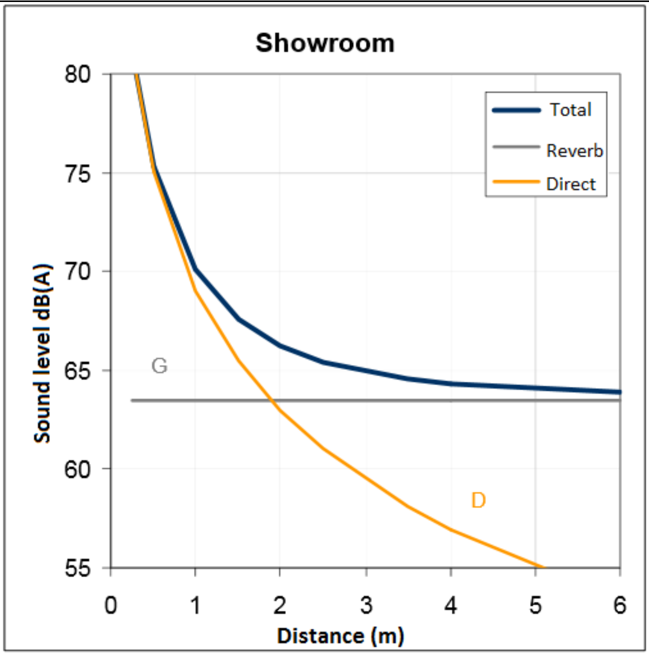
In an average living room the total reverb time amounts to around 0.5 s. That is relatively short. Because of the relatively small volume of a living room the sound cannot escape and this translates in a relatively high reverb volume. This is illustrated in fig A. Given a distance of only 1 meter of the source, the reverb sound level already exceeds that of its source. The total sound of direct +reverb amounts to around 74 dB. The human ear cannot distinguish between the direct and indirect sound waves due to the incredibly short reflection times inside a living room. The reflections and the source sounds are perceived to be just one sound.

Show room

For larger spaces, like a show room in a piano trading company, a much larger volume is available (around 580 m3 for a space 15 x 12 x 3.2 m3). The sound can expand further across the space which results in a much lower reverb sound level (around 9 dB lower than a living room). The totaled sound level at 1 m distance from the source is then around 70 dB. In comparison to an identical sound produced in a living room, the sound level is then 4 dB lower. Additionally, the first reflection off a wall inside a piano showroom is usually far less significant as pianos are mostly displayed in the middle of the show room and not positioned against a wall. It is not easily determined what precise effect this has acoustically and it would need further detailed analysis that would be outside of the scope and purpose of this report. For now the significant detail is the 4 dB difference at 1 m distance to be considered.

Living room	**Show room**
Volume 90 m3 (9 x 4 x 2.5 m). Reverb T_{60}=0.5s 1st reflection rear wall and ceiling LARGE Reverb level higher because of smaller space	Volume 580 m3, reverb T_{60}=0.7s 1st reflection ceiling and rear wall SMALLER Reverb level lower because of larger space.
	


Living room
Sound level dB(A)
80
75
70
65
60
55
0
1
2
3
4
5
6
Distance (m)
Total
Reverb
Direct
G
D


Showroom
Sound level dB(A)
80
75
70
65
60
55
0
1
2
3
4
5
6
Distance (m)
Total
Reverb
Direct
G
D