

# The effect of inharmonicity on the perceived quality of piano tones

Bruno L. Giordano (1), Davide Rocchesso (2)

(1) Department of General Psychology, University of Padova, Italy (email: brungio@tin.it)

(2) Department of Science and Technology, University of Verona, Italy (email: rocchesso@sci.univr.it)

## Abstract

The relationship between spectral inharmonicity and the perceived timbre naturalness was investigated. Quantitative methods are used to establish a measure of this relationship for different fundamental frequencies. Qualitative data are collected to study in depth the perceptual dimensions used by the subjects to judge the perceived naturalness in piano tones.

## 1 Introduction

Inharmonicity of piano tones is due to the stiffness of the strings, which causes the frequency of the vibration modes to be higher than the frequency of perfectly harmonic partials. The simulation of the dispersion of the partials by mean of physical modelling could require the use of high order filters so that computational resources needs are excessive for real-time synthesis. As a consequence measurements of the minimum amount of inharmonicity required to the conservation of a piano timbre judged as natural or non synthetic are needed. Back in time Fletcher [1] pointed out how inharmonicity in piano tones is essential in order to preserve naturalness and timbre warmth. Rocchesso and Scalcon [2] found recently that the amount of inharmonicity required to preserve a natural piano timbre decreases with increasing fundamental frequencies. The general purpose of our investigation is to reply the findings of the cited studies enlarging the qualitative observations about the perceptual dimensions used by subjects to discriminate between natural and non natural piano timbres. This will however follow the acquisition of quantitative data effectuated by mean of the appropriate psychophysical techniques. In analysing collected data we will then verify the weight of the spectral centroid in determining subjects responses. A general finding in timbre perception studies is in fact that spectral centroid, a measure of the displacement of the high energy spectral components positively correlated perceived brightness, alone explains most of the variance of subjects responses in timbre discrimination tasks [3, 4, 5, 6, 7]. As this has been found using different sets of stimuli, our purpose is to verify the weight of this physical/psychological dimension in discriminating between the timbre of synthesised piano tones.

## 2 Synthesis

The synthesis of the stimuli has been driven by the sinusoidal representation of the signal extracted by analysing the notes C1, C2, C3, C4 and C5, with a fundamental frequency respectively of 32, 65, 130, 261 and 523 Hertz, played in a Schulze-Pollmann piano. For the analysis we used the program SMS based on the Deterministic plus Stochastic Model of Serra [8]. All stimuli were synthesised keeping the formant structure, the spectral bandwidth and the micro-variations in amplitude and frequency of the original reference piano tones. Inharmonicity has been decreased lowering the average frequency of all the partials above a variable cut-off frequency. The difference between adjacent partials above the cut-off frequency have been kept constant and equal to the difference between the last and the preceding one of the non manipulated partials. As independent variable we used the percentage of lowered partials out of the number of partials found in analysis: we will refer to this index as PH or percentage of harmonised partials. We preferred to use a relative variable, as the PH, in order to be able to compare the results obtained from stimuli with different fundamental frequencies and, because of sampling frequency limitations, with a different number of partials. We used PH's of 0, 25, 50, 75 and 100%. So a stimulus with a 0% PH is the original reference tone, while in a stimulus with a 100% PH the partials form an harmonic series, being their average frequency integer multiple of the fundamental frequency.

The elimination of the inharmonicity causes the perceived pitch to be lower than the one of the original tone. The deviation in the perceived pitch, consistent only for low fundamental frequencies and for high PHs, isn't however greater than 50 cents under the best conditions. For this reason we didn't equalise the pitch of the stimuli synthesised from the same original piano tone, as in previous works is found that little pitch differences do not

affect the timbral relationships among the stimuli (i. e. their positions inside the computed timbral space) [9]. Overall duration of all the stimuli has been equalised to 2 seconds applying a linear 200 ms. fadeout.

### 3 Experimental Procedure

To collect data we used the method of paired comparisons plus an additional procedure similar to those used in classical psychophysics to measure absolute thresholds. With the method of paired comparisons, we can obtain an order and a distance relationship for all the stimuli with the same fundamental frequency with respect to the psychological continuum of the perceived timbre naturalness. With the second procedure we estimate an absolute threshold for timbre naturalness in terms of PH, the threshold itself defined as the PH below which the stimuli are judged as having a natural piano timbre at least 50% of the times. In the first case subjects have to say which of the two coupled stimuli possess the more natural timbre, while with the second procedure subjects judge one stimulus at a time saying if the listened tone have a natural piano timbre or not. Coupled stimuli were separated by 1000 msec. of silence. After the two procedures had been applied subjects were interviewed about the criterions followed in executing the preceding tasks. We were particularly interested in the perceptual/phenomenal nature of the main dimensions of timbre used by subjects in order to discriminate between natural and non natural tones. For all the tests we used the same 13 subjects, all Piano graduates of Padua Conservatory. The overall duration of the experiment was almost of 30 minutes.

### 4 Results and discussion

Apart from the particular fundamental frequency, the first evident effect of increasing the PH is a progressive fall of the related scalar values, which stands for a decreasing of the perceived timbre naturalness (Figure 1).

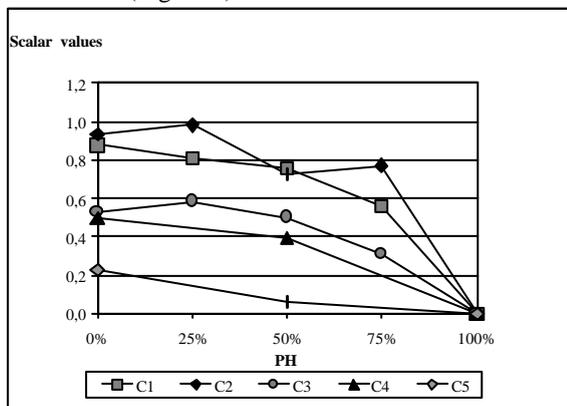


Figure 1: Scalar values for all the tested stimuli.

All the correlations between the scalar values and the PH, calculated for the different subsets of stimuli, synthesised manipulating the same original tone, are significant (Table 1).

Note	Correlation (r)	p-value
C1	-0.890	0.043
C2	-0.892	0.082
C3	-0.884	0.046
C4	-0.930	0.022
C5	-0.892	0.042

Table 1: Correlation between the scalar values and the PH for the different subsets.

Another information can be derived from the range of variation of the scalar values associated to all the stimuli synthesised by manipulating the same original piano tone. Defined the range as the difference between the highest and the lowest of the considered scalar values, the higher the range the harder is to discriminate between the stimuli in respect to the considered psychological attribute. The tendency in our data is that as the fundamental frequency increases the range of the scalar values decreases. The measured correlation between these two variables is  $-0.855$  ( $p=0.002$ ). So we can conclude that for higher fundamental frequencies the lowering of the spectral inharmonicity has little or no effect on timbre naturalness and on timbre itself.

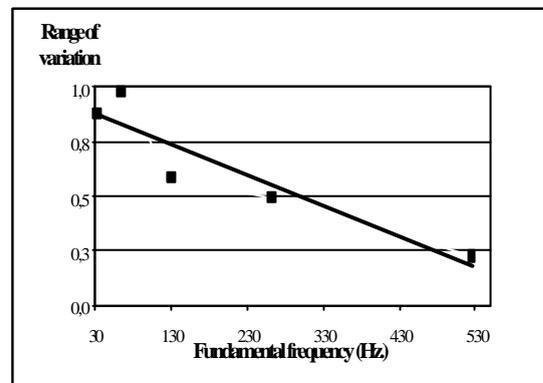


Figure 2: Range of variation of the scalar values versus fundamental frequency. A tendency line is displayed.

The decreasing in timbre naturalness with increasing PH is consistent with Rocchesso and Scalcon data [2]. The decreasing of the range of the scalar values with increasing fundamental frequencies agrees with Fletcher's observation that the effect of inharmonicity in determining the liveliness of the perceived piano timbre is important only in the lowest three octaves [1]. The results concerning the determination of an absolute threshold indicate in general that for higher fundamental frequencies we can eliminate an increasing amount of inharmonicity without any

appreciable effect on the timbre naturalness. The general tendency found in data is in fact a relation of direct proportionality between the threshold in PH and the fundamental frequency. Nevertheless all the subjects judged as having a particularly low-quality piano timbre all the stimuli synthesised from the notes C3 and C4 (medium-high range). For this reason thresholds obtained for C3 and C4 are lower than zero, which is a nonsense.

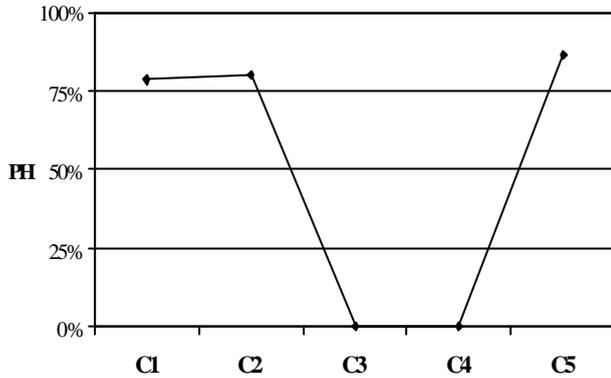


Figure 3: Absolute threshold for the perceived timbral naturalness in PH for the different notes.

This measurement artefact is surely due to the use of the brand Schulze-Pollmann for the recordings of the original piano tones: some of the subjects recognised the brand saying that it's timbre is typically non-natural in the middle-high range. For this reason successive measurements with a different piano model are required.

The correlations between the average values of the spectral centroid of all the stimuli and the relative scalar values, measured for all the subsets, aren't significant. This indicates that subjects in judging the perceived timbre naturalness used different perceptual dimensions than the one of the spectral brightness.

Note	Correlation (r)	p-value
C1	-0.806	0.099
C2	-0.714	0.176
C3	-0.857	0.063
C4	-0.682	0.522
C5	0.356	0.768

Table 2: Correlation between the scalar values and the mean spectral centroid

This conclusion is consistent with the analysis of the interviews conducted after the experimental phase. The two most important indexes used in discriminating between natural and non natural piano timbre have in fact been the rapidity of the attack (medium-high notes were judged as having a plucked-like timbre, similar to that of the clavichord) and the quantity of tempo-variance of

the signal (subjects, especially for PHs of 100% reported a strong presence of, as they defined them, "beats"). Even if difference in timbre brightness among the stimuli were clear and present it is evident that subjects disregarded them as being fundamental in discriminating between the timbre of the listened stimuli. These latter findings lead us to think, as Bregman himself did [10], that the indexes used by subjects in timbre discrimination or timbre scaling tasks are heavily dependent on the particular set of stimuli used.

## 5 References

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