GUITAR MULTIPHONICS: INFLUENCE OF AMPLIFICATION

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Abstract: **The amplification of sounds of guitar multiphonics had not been explored until now. We recorded and spectrally analyzed this kind of sounds of unusual colours, to investigate the influence of amplification with close microphone placement on the audibility of their weaker main components. The results show that novelty is introduced for the majority of the sounds investigated, because some of their main components are otherwise not audible in a concert room, regardless of its size.**

1. INTRODUCTION

The technique of multiphonics is widely popular in woodwind instruments. In the past years it has gained attention in low-pitched bowed strings, and in the piano and the guitar it is slowly coming out of the shadows [1]. A lack of interest on the instrument by non-guitarist composers may explain the lack of guitar research [2].

On the guitar, the technique works much better on wound strings.[1] It consists, as in the case of harmonics, in damping out some of the string's vibrational modes (v.ms.) by lightly touching the string at certain locations during or after its excitation (or both). What objectively distinguishes both techniques is that, whereas with harmonics the filtering is systematic in respect to vibrational-mode number, with multiphonics it is not. This facilitates our nervous system in the grouping of the partials of the resulting sound into subsets of fundamentals – hereafter *main partials* – and their overtones. In case this takes place, there is the perception of multiple pitches [3]. The highest main partial found in multiphonics charts [4, 5, 6] is partial 19. For one of these charts there is a justification, found in another section of the book: the authors find impracticable to play harmonics above partial 19 on the bass strings [6].

Like with harmonics, the maximum overall loudness of the sounds of multiphonics is lower than that of conventional sounds. Moreover, the relative loudness (r.l.) of some of the main partials may be quite low, either due to strong damping of the v.ms or to their (intrinsically) lower excitation strengths. For the frequency range of the investigated sounds, the preferential absorption of the higher frequencies by the air [7] does not play a major role. Nevertheless, the level of the lower-intensity components reaches the threshold of hearing at a shorter distance from the guitar. It is then surprising that none of the reviewed pieces [8] was scored for amplified guitar, except for one, most certainly to make the guitar at all audible among the other instruments of the ensemble. Amplification of the sounds with close microphone placement should improve the audibility of the weaker main partials. Moreover, with different microphone placements along the guitar, it may be possible to obtain different loudness balances of the main partials, as the parts of the guitar radiate preferentially different frequency ranges [9, 10]. Colours and, when perceivable, pitches would then be emphasized or even revealed to an audience. This would introduce novelty, which is important to avoid connotation with the non-amplified sound [3].

2. METHODOLOGY

Each player has his/her own instrument, physiognomy and idiosyncrasies, and this may influence the resulting sounds. Thereby, to investigate the influence of amplification on the audibility of the weaker main partials, it was used a sample of guitarists playing, in individual recording sessions with close microphone placement at selected positions along the guitar, a set of takes of string 6 lightly touched at established locations along the string. The recordings were spectrally analyzed at a selected time segment, and the data was treated and evaluated.

Conditions for the sample and for sound production, recording and analysis were established, and the main partials at each location were predicted up to partial 39 [11].[2] Given that one of the applications of the results are pieces for live performance, the elements of the convenience sample (also a purposive sample, for quality in the executions) sample were told that a concert situation was desired. For the same reason the recordings were made in a large studio also used as concert room. The recorded data was spectrally analyzed at a time segment by the end of the decay of the higher partials. The period of time up to this point of the sounds' decay was the period considered for the evaluation of the reliability of the main partials.[3] These results are also presented in this paper and are based on the number of guitars and microphones, in the data of which a partial was detected. Non-detected partials were considered not reliable.

Although equal-loudness curves are for pure and isolated tones, loudness differences from the 40 phon curve (the reference for low-level tones [13]) were used to determine, for the data of each location, the most common loudest-perceived main partial – hereafter *perceptibly loudest partial* (p.l.p). The r.l. of each of the other main partials to the p.l.p. was calculated. Assuming the p.l.p. to lie on the 40-phon curve, 10-phon-spaced normalized equal-loudness curves were plotted together with the r.l. values, in order to visually evaluate their *perceived relative loudness* (p.r.l.) and respective variation with microphone placement.[4]

The p.r.l. of a partial's r.l. depends on the frequency of the p.l.p. being investigated, the For the frequency range of the partials lower the frequency of the p.l.p., the higher the p.r.l. Some partials may not be perceived or be perceived softer due to the masking effect. Total masking by the p.l.p. was taken into account using assumptions based on values for the masking of pure tones by pure tones [15] together with values of the 40-phon curve. The p.r.l. was considered to be: strong, moderate, weak, or very weak when it varies approximately between 30 and 40 phon, 20 and 30 phon, 10 and 20 phon and 0 and 10 phon, respectively. Partials with a p.r.l. of 0 phon or less, or totally masked were considered not perceivable. For a distance of 3.8 m the attenuation of sound is -10 dB, whereas for distances of 12 m and 38 m the attenuation is -20 dB and -30 dB, respectively [7]. This means that, approximately, without amplification, very weak partials are audible up to 4 m, and weak and moderate-p.r.l. partials are audible up to 12 m and 38 m, respectively. Very weak partials should then only be perceived by the guitarist, and weak partials should be hard to perceive by an audience which should also have difficulty in perceiving moderate-p.r.l. partials in the back of medium-sized room. In larger rooms, strong partials should also be lost.

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[1] Usually strings 4, 5 and 6. String 3 is sometimes also wounded.

[2] The cited paper mentions recordings of strings 4 and 5, the use of other kind of microphones, and the analysis at another time segment. This is, however, not dealt with in the present paper.

[3] Reliability is "the ability of a system or component to function under stated conditions for a specified period of time" [12].

[4] A loudness difference of -10 phon is perceived for single tones as half as loud [14].

3. METHOD

Professional and semi-professional guitarists were invited by e-mail to participate in a two-hour paid recording session, for which they should prepare as for a concert. When they agreed to participate they received by e-mail a document in English with an abstract of the project, some information on the study and playing instructions. Three professional guitarists and two master-level students with experience in the professional music world (four male and one female), all right-handed, took part in the recording sessions. Each guitarist used his own (concert) guitar tuned to 442 Hz. All guitars had a string length of 65 cm. One guitar was constructed in 1994 and the years of construction of the others varies between 2004 and 2010. The tension of the strings was high in three of the guitars and medium/high in the other two, and their usage varied between none and two months of moderate playing. Three guitarists used a footstool and two used a leg support.

When used as a concert room, the large studio has seating for about 150 persons. During the recording sessions it had no chairs. The wooden walls of the half of the room to which the microphones were pointing at were covered with cloth curtains. A carpet was placed on the area (wooden floor) where the guitarists and microphones stood. The guitarists sat on a piano bench.

Table 1 describes the recording and editing apparatus. The microphones (with a sensitivity of 40 mV/Pa) were set to the omnidirectional mode and placed at a distance of 30 cm at the following positions: in front of fret XII aiming at it (M1); in front of the sound hole aiming at it (M2); and above the neck aiming at it (M3). The gain of the microphones was adjusted to have approximately the same pick-up level: M1's gain was 31 dB, M2's gain was 28 dB, and M3's gain was 37 dB. The sounds at each location – 88 in total – were played one after another in one take starting from the lowest location. As other sounds were recorded in the sessions, the number of takes was minimized to three. With one guitarist it was only possible to record two takes due to lack of time. Before playing each sound, the guitarists spoke the location's identification, and were asked to wait about 0.5 s thereafter. When playing, they were asked to: mute all other strings, touch briefly with a pressure similar to the reference pressure, pluck *forte* near the bridge with nail and rest stroke, and let the sound decay for about one second. After playing the sounds, they were asked to: maintain the left hand near the fingerboard, take time to prepare the location that followed, and wait about half a second before proceeding. No mention was made to the finger that should touch the string. The (amplified) signals of the microphones were recorded in separate tracks at a frequency of 48 kHz and with a 24-bit encoding. The sound files of the takes were cut into individual files, one for each location. The pre-scratch [10] was left out, in order to minimize differences in the time span between the beginning of the file and the attack.

The application Pm2 (version 1.6.25) – one of the kernels of IRCAM's Audiosculpt – was used for the spectral analysis. This command-line application takes advantage of Unix shell functionality, allowing thus batch processing, for which no other option was found at the time. Each sound file was subjected to a "Chord Sequence" analysis in the Inharmonic Partial Averaging mode. This calculates over a time segment the average of values obtained with the Partial Tracking Analysis in the inharmonic mode [16]. The values used for the analysis parameters can be found in Table 2. The SDIF analysis files were converted to text files with Audiosculpt's droplet SDIFToText. The frequency and amplitude values of the text files were copied to spreadsheets and converted into their factors to the theoretical open-string fundamental frequency, full-scale loudness levels (dBFS), respectively. The level values of M1 and M3 were normalized to those of M2.

Table 1: Recording (R) and editing (E) apparatus

Hardware/Software	Manufacturer | Model
Microphones	Sennheiser | MKH 800
Microphone pre-amplifier	Stagetec | Nexus Xmic
Audio format-conversion and routing system	Stagetec | Nexus
Digital audio workstation (R)	Digidesing[5] | Pro Tools HD3
Interface	Digi 192
Software version	9
Digital audio workstation (E)	Digidesing | Pro Tools LE
Interface	Digi 002
Software version	8.0.3

Table 2: Analysis parameters and respective values

Parameter	Value
Maximum Number of Partials	39
Amplitude Threshold	-120 dB
Use Markers of Type...	Hand Added: 505-569 ms
Relative Min. Partial Length	51% [of time segment]
FFT Settings:	
Window Size (WS)	78 Hz/3077 samples/64.1 ms
Window Type	Blackman
Window Step	Manual: 12.5% of WS
FFT Size	32x (131072 bins)
Peak Connection:	
Relative Frequency Deviation	0 cents
Constant Frequency Deviation	8.0 Hz
Relative Amplitude Deviation	50%
Source Partial Neighbors	1
Target Partial Neighbors	3
Partial Connection:	
Time Gap to Connect Over	0.015 s
Freq. Gap to Connect Over	0.0 cents
Minimum Partial Length	0.007 s

The data of the predicted main partials was then manually sorted (single-take detections were discarded); the p.l.p. at each location was determined; and r.l. mean-values and their standard deviations were calculated for the data of each guitarist and of the sample at each microphone. These values were plotted together with equal-loudness curves extrapolated [17] from norm ISO 266:2003 values [18] and normalized to the p.l.p. As exemplified in Figure 1,[6] the sample's graphics also include the number of guitars, in the data of which each partial was detected. The reliability of the partials was considered to be: high when they were detected in the data of all microphones of at least four guitars; moderate when detected in the data of two microphones of at least four guitars, or of all microphones of three guitars; very low when detected in the data of only one guitar; and low for all other cases. P.r.l. differences of about 5 phon or higher between microphones were flagged for partials with high or moderate reliability and detected in the same number of guitars.

[5] Presently *Avid*.

[6] The choice of this example is related with a theoretical example of a previous paper [3].

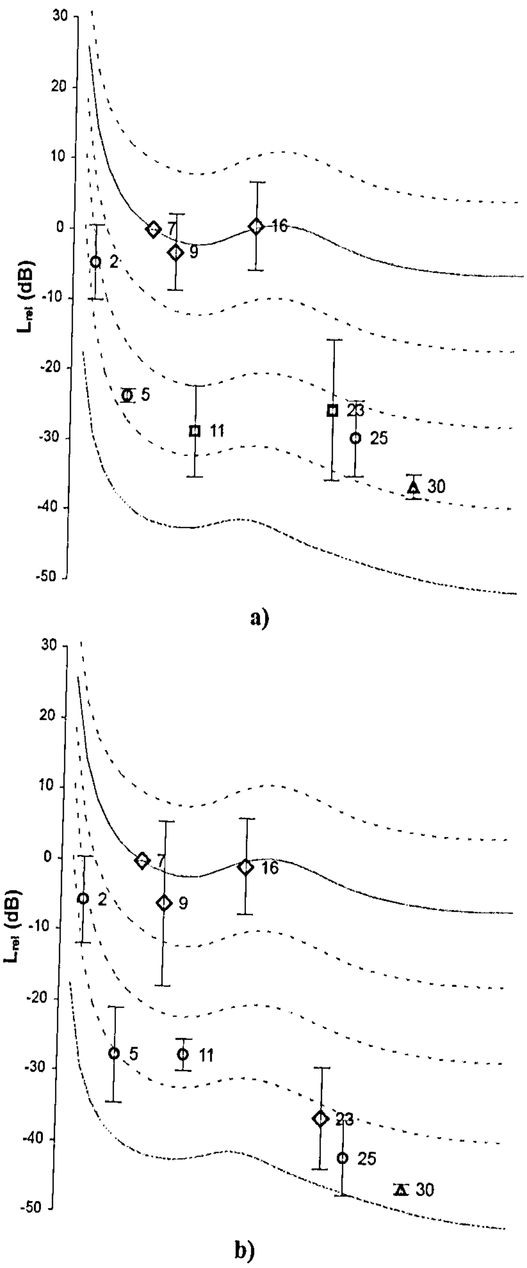

Figure 1: Relative loudness (L_{rel}) and its standard deviation, and perceived relative loudness (L_{rel} in relation to the normalized equal-loudness curves; the lowest curve is the 0-phon curve) of the main partials of the sounds at fret X on string 6 at (a) M1 (fret XII) and (b) M2 (sound hole). Lozenge, square, circle and triangle correspond respectively to detection in the data of five, four, three, and two guitars.

Table 3: Average reliability-distribution (%) among the investigated locations on string 6 of the sounds' predicted main partials 0.5 s after the attack

Partials' reliability	Partial number					
	1	2-18	19-25	26-30	31-37	38, 39
High	21	75	29	0	0	0
Moderate	0	13	28	3	0	0
Low	21	11	37	67	14	0
Very low	21	1	6	21	37	0
Not reliable	37	0	0	9	49	100

Table 4: Average p.r.l.-distribution (%) among the investigated locations on string 6 of the sounds' reliable main partials 0.5 s after the attack

Partials' p.r.l.	Partial number			
	1	2-16	17-21	22-37
Strong	17	[illegible]	5	4
Moderate	17	18	22	4
Weak	17	21	[illegible]	23
Very weak	50	8	[illegible]	43
Not perceivable	0	16	19	19

Table 5: Number of the reliable main partials in each p.r.l. category 0.5 s after the attack of the sounds produced at the investigated locations on string 6

Partials' p.r.l.	Location distribution (number of locs.)				
	55% (48)	2% (2)	9% (8)	20% (18)	14% (12)
Strong	1-3	5	2/3	1	1
Moderate	1-5	2/5	0	0	0
Weak	0*-5	0	1-6	1-4	0
Very weak	0"-5	0	0-3	0-6	0
Not perceivable	0-4	0	0/1	0-5	1-6/12

*3/"10 locations but always one of the two categories

4. Results

Table 3 presents an overview of the reliability results. Except for partial 1, the majority of the predicted main partials up to partial 18, as well as more than the half of partials 19 to 25 have high or moderate reliability. When reliable, partials 26 to 37 have always low or very low reliability but partials 26 to 30 were, nevertheless, systematically detected in the data of two guitars. Partials 38 and 39 are not reliable.

An overview of the p.r.l. results at M1 can be found in Table 4. Except for partial 1, over half of the predicted main partials up to partial 16 have high or moderate p.r.l. Partials 17 to 21 have hardly a strong p.r.l. but partials 18 and 21 are, nevertheless, the p.l.p. at two locations. Partials higher than partial 21 have always a weak or very weak p.r.l., or are not perceivable.

The flagged p.r.l. differences between M2 and M1 and between M3 and M1 are always negative for partials above partials 18 and 12, respectively.

Table 5 presents an overview of the number of main partials in each p.r.l. category at M1. For 12 of the 88 investigated locations, perceivable main partials other than the p.l.p. were not detected. Of the other 74 locations, 72 give rise to sounds that contain main partials with weak and/or very weak p.r.l. Sounds containing more than one main partial with strong or moderate p.r.l. arise at 58 locations. Main partials with a moderate p.r.l. were not detected for sounds at 26 of the locations with more than one perceivable main partial (the case of the location of Fig. 1). For the sounds at two locations (situated near the nut), the main partials are partial 1 (only present at that kind of locations) and partials above partial 21, and all have strong or moderate p.r.l.

5. Discussion

The sounds at most locations contain weak and/or very weak main partials. Therefore, amplification of these sounds introduces novelty, even in a small concert room, at least with high-sensitivity microphones. To a lesser extent, amplification also introduces novelty by allowing a longer fruition of the partials, especially fast-decaying partials.

Only total masking by the p.l.p. was taken into account. Partials might, however, be totally masked by other equally strong partials (like those in Figure 1), or be partially masked, and thereby have a lower p.r.l.

The locations with only one perceivable main partial are locations at or very near a node of v.ms. 2, 3, 4, 5, or 6. At those locations, v.ms. non-multiple of these modes are very easily damped out, and thus the technique of harmonics ends up being played.

While it is true that it is not practical to play higher harmonics, the results show that it is not impracticable to play sounds of multiphonics with partials higher than partial 19. There are, however, fewer sounds in which these partials are highly or moderately reliable and have a strong or moderate p.r.l. The frequency of partial 19 of string 6 is over 1500 Hz. This value has been pointed out as the value above which the influence of the string-vibration component perpendicular to the soundboard – enhanced by a rest stroke – loses significance in the direct driving thereof [19]. This could contribute to the lower reliability and p.r.l. of the main partials above partial 18. At the soundhole microphone (M2) their p.r.l. is even lower because the enclosed air radiates preferentially lower frequencies and thus the p.l.p. is louder. The negative p.r.l. differences of partials above partial 12 at the neck microphone (M3) could be due to the frequencies of the partials being close to body-resonance frequencies, the radiation of which would lose strength at the neck.

The microphone at fret XII (M1) presents then a better balance between lower and higher partials. The purpose of the neck microphone was mostly due to the recording of other kind of sounds. In regard to the sounds investigated, this microphone picks-up essentially the body radiation, because the neck not only radiates less intensively than the other parts, but also radiates preferentially in a frequency range mainly above that investigated. Needing a higher gain, the neck microphone captures more room reflections, especially those of the noise of the attack, as perceived in the recordings.

6. Conclusion

To our knowledge, this is the first study of its kind on guitar multiphonics. The results show that, even in a small concert room, amplification introduces novelty for the majority of the sounds investigated, because some of their main components are otherwise not audible. The results also provide information on the reliability of the main components.

Future work involves comparing these results with those from (simultaneous) recordings with less sensitive microphones with omnidirectional and with cardioid pick-up patterns. Strings 4 and 5 shall also be investigated.

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