Analytical and Perceptual Detection of Rustle in Stationary Violin Tones

Jan Stepanek, Zdenek Otcenasek and Ondrej Moravec
Music Faculty, Academy of Performing Arts, Prague, Czech Republic
(Hudebni fakulta AMU, Malostranske nam. 13, 118 00 Praha 1, CZECH REPUBLIC)
E-mail: STEPANEK@H.AMU.CZ

Summary: 'Admixtures' in stationary violin tones are described by listeners as 'rustle'. Recent research has shown that the main source for 'rustle' in the D6 violin note (fundamental frequency 1175 Hz) is in the frequency band from 230 to 800 Hz. Perceptual properties of spectral components responsible for 'rustle' are studied. Three experiments were performed: 1) detection of the threshold of hearing isolated 'rustle' components; 2) detection of the threshold of perception of 'rustle' components in the presence of the harmonic part of the tone with SPL equal to 50, 60, and 70 dB; 3) detection of the amount of 'rustle' in the signal. Results suggest that the threshold of hearing 'rustle' does not differ significantly from the threshold of hearing narrow band filtered white noise, that 'rustle' components are masked by the harmonic part of the signal, and that for a *mezzo forte* dynamic (about 70 dB SPL) 'rustle' is perceptually salient for levels above 30 dB (5 dB above threshold of 'rustle' perception).

1. INTRODUCTION

1.1 'Rustle' as an attribute of timbre of stationary violin tones

Word descriptions of timbre of five different notes were obtained in listening test during the investigation of timbre of stationary violin tones. Basic perceptual dimensions of stationary violin sounds were established by comparing perceptual spaces based on the results of the listening tests [1].

The word 'rustle' together with a group of relative words was used by the subjects in describing 'admixtures' in tones. The group of relative words with mutually significant correlations of frequency of occurrence for individually tested tones consists of the following: 'rustle', 'sandy', 'hissy', 'scrubs', 'dusty', and 'horse hair'.

A marked increase in overall frequency of occurrence of words from the group 'rustle' was found for the highest tested D6 note. Some physical attributes of the stationary part of the violin tone, the cause for the perceptual phenomenon described by the word 'rustle', were described in [2, 3].

1.2 Results of recent experiments

On the basis of correlation analysis it was shown that in the stationary violin D6 note (fundamental frequency 1175 Hz) at least two possible sources for 'rustle' exist [2, 3]: levels of frequency components below the fundamental lying in the frequency band from 200 to 900 Hz (third-octave bands with centers 250, 315, 400, 500, 630, and 800 Hz), and levels of harmonics from the seventh to the fourteenth (frequency band from 8 to 17 kHz).

Complementary listening tests were carried out on five original tones (one with a low, two with a medium, and two with a high frequency of overall occurrence of words from the group 'rustle') and signals prepared by filtering original tones. Suppression of levels in the band from 200 to 900 Hz (bandstop filtering), in the band above 8000 Hz (lowpass filtering), and in both bands was carried out.

A dissimilarity pair test showed that there was a greater change in timbre with the suppression of components below the fundamental than of higher harmonics [2, 3]. A verbal attribute magnitude estimation (VAME) test of 'rustle' revealed that the magnitude of 'rustle' decreased only in signals with suppression of components below the fundamental, namely in the band from 230 to 800 Hz [2, 3]. Time flows of levels in this band are aperiodic, random, and with negligible trends.

2. METHODS AND RESULTS

2.1 Stimuli and procedures

Previous tests were performed with headphones on partly manipulated and/or filtered recordings of violin tones [3, 4]. The SPL of the stationary part of tones was approximately 70 dB, a level corresponding to recording conditions in an anechoic room: *mf* playing, 3 m distance from the microphone.

A new set of listening tests was carried out in order to obtain a more detailed perceptual description of 'rustle'. Three types of signals were used:

1. **Original tones** used in tests described in [2, 3], numbered here from 1 to 5. The overall frequency of occurrence of the word ‘rustle’ found in the previous test is indicated in TABLE 1.

TABLE 1. Overall frequency of occurrence of the word ‘rustle’ for signals used in listening tests.

Signal No.	1	2	3	4	5
Frequency	0	13	16	20	22

2. **Harmonic parts** of tones: signals prepared by bandstop filtering of original tones in the band from 230 to 800 Hz (‘rustle’ suppression as in previous tests). A Chebyshev type II bandstop filter was used to preserve amplitudes of all individual harmonics starting from 1175 Hz (FIGURE 1).

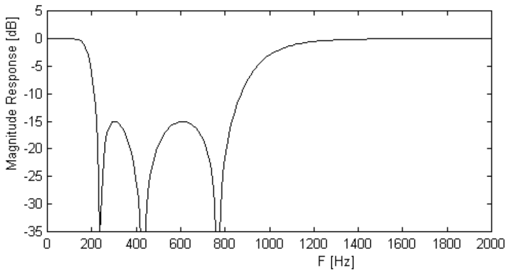

FIGURE 1. Chebyshev type II bandstop filter, corner frequencies: 230 and 800 Hz, attenuation: 15 dB.

3. **‘Rustle’ components** of tones: signals prepared by bandpass filtering of original tones in the band from 230 to 800 Hz. A Chebyshev type II bandpass filter was used for the suppression of amplitudes outside this band (FIGURE 2). A signal with white noise filtered using the same filter was also prepared. The filter was used repeatedly to achieve sufficient suppression.

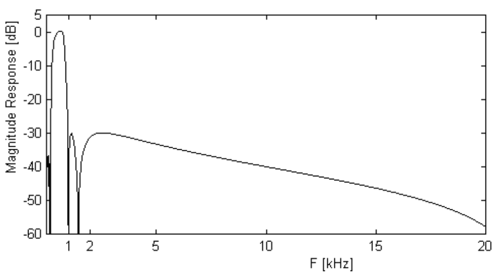

FIGURE 2. Chebyshev type II bandpass filter, corner frequencies: 230 and 800 Hz, attenuation: 30 dB.

Monophonic signals were stored in WAV format on PC, and the duration of each signal was 1135 ms. Tests were performed in a MATLAB environment, enabling easy manipulation of signals and control of their SPL. Closed Sennheiser HD 250 linear II headphones were used, and the SPL of all signals was calibrated.

Three listening tests described further were performed by eight experienced subjects (sound engineers and sound designers) aged from 25 to 55 with a normal hearing threshold.

2.2 First experiment: Threshold of hearing ‘rustle’ components of violin tones

Signals with only ‘rustle’ components and with narrow band filtered white noise were used in this experiment. Subjects detected the threshold of hearing each signal. SPL of signals changed in steps of 1.5 dB. The simple up-down method for detecting the hearing threshold was used [5]. Results of this experiment are presented in FIGURE 3.

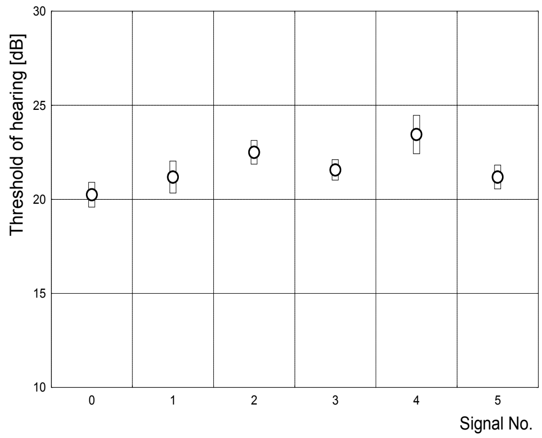

FIGURE 3. Threshold of hearing for narrow band filtered white noise (230-800 Hz) - signal No.0, and for ‘rustle’ components of violin tones - signals No.1-5. The circle demonstrates subject-averaged threshold; bars indicate standard error.

2.3 Second experiment: Threshold of perception of ‘rustle’ with the presence of a harmonic signal

The ‘mixed’ signal was created consisting of a harmonic part and ‘rustle’ components. Harmonic parts of tones were presented at a constant SPL (levels of 50, 60, and 70 dB were used), with a corresponding signal of ‘rustle’ components. Subjects detected the threshold of perception of ‘rustle’ components in a ‘mixed’ signal, where the SPL of ‘rustle’ components changed in steps of 1.5 dB. The simple up-down method for detecting the hearing threshold was used [5]. Results of this experiment are presented in FIGURE 4.

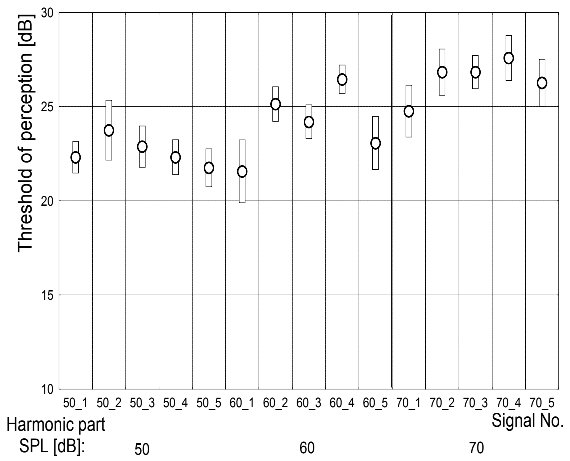

FIGURE 4. Threshold of perception of ‘rustle’ with presence of harmonic signal of constant SPL. The circle demonstrates subject-averaged threshold; bars indicate standard error.

2.4 Third experiment: Perceptual adjustment of the SPL of ‘rustle’ components

The first signal used in the pair test was an original tone, the second signal consisted of a ‘mixed’ signal (as in a second experiment). An SPL of 70 dB for both original tones and harmonic parts was used. The subjects’ task was to adjust the ‘rustle’ components in the second ‘mixed’ signal to be as perceptually similar as possible to the first signal. The SPL of the ‘rustle’ components was adjustable in steps of 1.5 dB. Results of this experiment are presented in FIGURE 5.

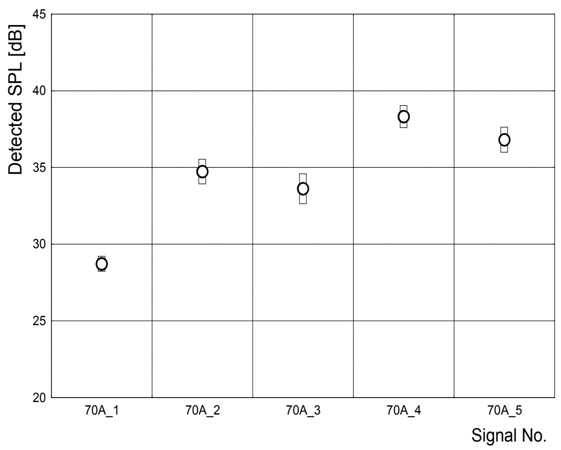

FIGURE 5. Detected SPL of ‘rustle’ components in a ‘mixed’ signal, perceptually adjusted to the amount of ‘rustle’ as in original tones. The circle demonstrates subject-averaged SPL; bars indicate standard error.

3. DISCUSSION

3.1 Dependence of the ‘rustle’ threshold on the presence of a harmonic signal

For the comparison of thresholds obtained in the first and second experiments, the Wilcoxon Test for differences between threshold mean values in the groups of signals 1 - 5, 50_1 - 50_5, 60_1 - 60_5, and 70_1 - 70_5 (dependent groups) was used. Results are indicated in TABLE 2 together with results of the Mann-Whitney U Test (MW) and Wald-Wolfowitz Runs Test (WW) for signal No. 0 and the group of signals nos. 1 - 5 (independent groups). The MW Test occasionally provides a strong basis for rejecting the hypothesis of equality of means.

TABLE 2. P-levels of differences of threshold mean values in groups of signals from the first and second experiment. Significant p-levels are indicated in bold.

Group of signals	0	1 - 5	50_1 - 50_5	60_1 - 60_5	70_1 - 70_5
Threshold mean	20.2	22.0	22.6	24.1	26.5
Difference p-level	MW: 0.051 WW: 0.21	0.30	**0.01**	**0.00**	

The presence of a harmonic signal or of its SPL increase raises the threshold of hearing for ‘rustle’ components. The threshold increase grows with increasing SPL of a harmonic signal, thereby rendering it significant. This indicates that the harmonic signal masks ‘rustle’ components to some degree.

The thresholds of hearing narrow band filtered white noise and ‘rustle’ components do not differ significantly.

3.2 Dependence of ‘rustle’ threshold on time flow or the spectral composition of ‘rustle’ components

‘Rustle’ components in individual tones must differ in time flow or spectral composition because they are perceptually similar, yet not identical. The question of the influence of different ‘rustle’ components on the threshold can be answered by the Kruskal-Wallis ANOVA Ranks Test or the Median Test applied consecutively in each group of signals 1 - 5, 50_1 - 50_5, 60_1 - 60_5, and 70_1 - 70_5 (independent samples). Results are indicated in TABLE 3.

TABLE 3. P-levels of threshold dependence on an individual signal for four groups of signals.

Group of signals		1 - 5	50_1 - 50_5	60_1 - 60_5	70_1 - 70_5
p-level:	Kruskal -Wallis	0.27	0.93	0.12	0.65
	Median	0.37	0.98	0.44	0.87

The threshold of hearing or perceiving 'rustle' components is not dependent on time flow or spectral composition. 'Rustle' components are also perceptually similar to narrow band filtered white noise, but the thresholds do not differ significantly as shown in 3.1.

3.3 Discernability of the amount of 'rustle'

Subjects were able to compare the amount of 'rustle' in signal pairs very precisely, often with more certainty than setting the threshold. Levels detected are compared in TABLE 4 with levels of 'rustle' components in the frequency band from 230 to 800 Hz, calculated from spectra in original tones.

TABLE 4. A perceptually adjusted SPL of 'rustle' components (Detected level), SPL of original tones in the frequency band from 230 to 800 Hz (Spectral level), and overall frequency of occurrence of the word 'rustle' found in the previous test.

Signal	70A_1	70A_2	70A_3	70A_4	70A_5
Detected level [dB]	28.7	34.7	33.6	38.3	36.8
Spectral level [dB]	30.0	34.2	35.2	38.2	39.5
Frequency of 'rustle'	0	13	16	20	22

Detected levels in the perceptual adjustment experiment are in very good agreement with levels found in spectra of original tones. Both levels are in high correlation with the overall frequency of occurrence of the word 'rustle' used by subjects in the previous test [2].

3.4 Test Reliability

The tasks of subjects in the tests were not simple, especially in detecting the threshold of 'rustle' in the presence of a harmonic signal, because harmonic parts of tones also contained a certain amount of 'admixtures' [2, 3]. It was therefore necessary to work with experienced subjects, i.e. sound engineers and sound designers.

Only eight appropriate subjects were found for the tests; thus some criteria for assessing the reliability of the tests were used:

a) the correlation coefficient among results of all pairs of subjects was significant (less than 0.001 p-level),
b) two randomly selected subjects were retested after a four months interval, with results having a highly significant correlation (less than 0.001 p-level) with the original test.

4. CONCLUSIONS

The threshold of hearing or perceiving 'rustle' in the frequency band from 230 to 800 Hz in D6 stationary violin tones is not dependent on time flow or the spectral shape of 'rustle' components, and does not differ significantly from the threshold of hearing narrow band filtered white noise. The harmonic part of the signal (fundamental frequency 1175 Hz) masks 'rustle' components, with the masking effect increasing with a higher SPL of the harmonic part. The threshold of perception of 'rustle' for the signal with an SPL of approximately 70 dB is above 25 dB.

The amount of 'rustle' in stationary violin tones is detectable, and for signals with an SPL approximately 70 dB is perceptually salient for levels above 30 dB (5 dB above the threshold).

ACKNOWLEDGMENTS

The research was supported by the Ministry of Education and Youth of the Czech Republic (Project No. VS 96031).

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